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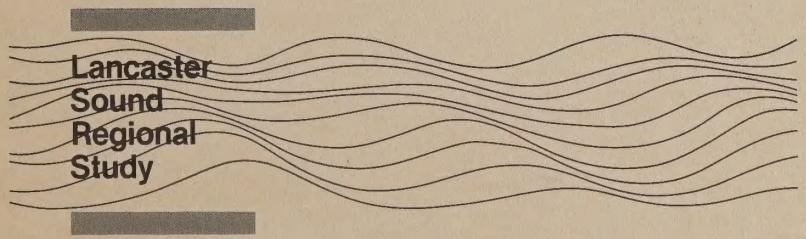
Selected Physical Characteristics

Background Report I



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Lancaster Sound Regional Study
Background Report No. I

SELECTED PHYSICAL CHARACTERISTICS OF THE LANCASTER SOUND REGION

Geology and Physiography
by B. R. Pelletier, Geological Survey of Canada, Department of Energy, Mines and Resources

Co-ordinator, Climate and Ice Climatology
D.C. McKay, Applications and Impacts Division, Atmospheric Environment Service, Environment Canada

Climate:
by J.B. Maxwell, Applications and Impacts Division, Atmospheric Environment Service, Environment Canada

Ice Climatology:
by W.J. Sowden, Ice Climatology and Applications, Atmospheric Environment Service, Environment Canada

Physical and Chemical Oceanography
by B.D. Smiley, Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, BC

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GENERAL INTRODUCTION

This report is one of five background reports prepared as part of the current study of marine and land-use options (Green Paper) for the Lancaster Sound region in the Northwest Territories. These reports are based on existing data, and together represent a body of information on which further discussion, analysis, and planning can be based. Information topics were selected on the basis of their relevancy to a particular resource use, or to provide a regional perspective of combined current or potential resource uses.

These reports and accompanying maps are being made available at this time in order to foster a thorough discussion by interested organizations, residents of the Lancaster Sound region, and concerned members of the public. Comments arising from the public discussion and any new information will be incorporated into a final report and map set to be published later.

The study of the Lancaster Sound region is being co-ordinated by the Department of Indian Affairs and Northern Development and carried out in co-operation with the Departments of Energy, Mines and Resources, Environment, Fisheries and Oceans, Transport, and the Government of the Northwest Territories.

Copies of other background reports are available by writing to:

Dr. Herman J. Dirschl,
Project Manager,
Lancaster Sound Regional Study,
Department of Indian Affairs and
Northern Development,
Room 631, North Tower,
Les Terrasses de la Chaudière,
Ottawa, Ontario K1A OH4

or by telephone at (819) 997-0223.

Other Background Reports

Report II: Selected Biological Characteristics

Report III: Socio-Economic Characteristics and Conservation Interests

Report IV: Non-Renewable Resources and Transport

Report V: Jurisdictions and Legislation

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Geology and Physiography
by B. R. Pelletier

REGIONAL CHARACTERISTICS

Geology

The basic precept for programs involving the development of natural resources as well as the protection of the environment is a sound understanding of the geological framework of the region under consideration. It is essential in environmental studies involving pollution prevention and clean up, restoration of coastal areas, and the unknown fate of the sea bed.

With regard to natural resources, a geological background is fundamental to the exploration and production of petroleum, natural gas, and mineral deposits. An inventory of quarry stone sites, and construction aggregates such as gravels and sands can be furnished. Geology can be used as a design tool for engineering works involving the following construction: access roads, staging areas for exploration and development projects, airstrips, pipeline and cable lays, and storage facilities.

Physiographic processes are part of geology and this is evident upon an examination of the geological formations and the manner in which running water and moving ice erode rocks into a varied landscape. These processes are consequent upon the action of geological forces that produce mountainous structures, low-lying valleys, and intermediate plateaus. Where river and glacier valleys follow geological structure their courses are rectangular, or trellis in pattern, but where they traverse gently folded and rounded hills they tend to be branching, or dendritic.

Surficial features such as soil slumping, induced by alternate freezing and thawing, are reasons for a geological approach to engineering problems requiring construction of installations on or near slopes in the Lancaster Sound region. Frost-heaved rocks are a surficial feature related to geological processes and engineering problems. Rivers and lakes must be mapped because they are direct suppliers of fresh water, while the

geological formations require study and mapping because they are both the containment and the conductor for ground water flow, except in the case where flow is inhibited by the presence of permafrost. This latter aspect of hydrology underscores the need to study permafrost and its relationship to bedrock, unconsolidated surficial sediments, and organic soil. In a companion geological study, so-called thermokarst topography (produced locally by melting of ground ice and subsequent settling of the ground) must be investigated, particularly in areas designated for construction, because of the dangers of unstable foundations and possible collapse.

In a less direct sense, geology can be applied to an understanding of vegetation patterns, as some plants grow only in certain types of soil (Map 2.14) underlain by, or derived from, specific rock types. Grazing animals may follow these patterns of lithologically related vegetation.

Over much of the landmass, deposits derived from river flow, glaciers, and mass wastage such as landslides and rock slides must be mapped and their origins traced. These unconsolidated sediments are potential sources of construction materials and are found commonly as outwash deposits in the forms of deltas, eskers, moraines, and talus. A less beneficial aspect may lie in the risk they may present to communities and engineering projects because of possible instability. A geological engineering survey should help to determine the degree of danger, if any.

Along the coast, adjacent cliffs and talus slopes must be examined and mapped geologically to determine their nature and extent. Some may be resistant and occur near shore, if not at the water's edge, and thus offer no space or feasibility for the construction of coastal installations and roads. Other coasts may be easily erodable and hence yield sedimentation problems to a marine site, particularly if situated in an up-current location from a proposed facility. In certain areas, flights of beaches are prominent features and offer a variety of amenable prospects; they are sources of aggregates for engineering works, they may be suitable for building access roads and airstrips, and they may also be suitable for extending communal and staging facilities for the support of adjacent marine terminals.

It is important to know the degree of slope of the beach face because of the need for a stable and accessible surface. In this respect, knowledge of the materials comprising the beach is important. The beaches, together with the local geological formations, must be mapped and the geology understood (Maps 1.3, 1.4, 1.5). As well, the coastal geologist must study the phenomenon of ice-pushed ridges and their effect on the beaches. Directly offshore are possible marine terminal approaches, turning basins, shoals, the littoral drift of sediments derived from eroding headlands, and the prospect of river and ocean currents that could induce sea-floor scouring and sedimentation in commercially and culturally important areas. Because of these economically mitigating factors in the coastal zone, such as shoals, erosion and sedimentation, a broad study embracing hydrography, geology, and engineering must be carried out to ensure a secure coastal activity.

The geological principles that apply to the land may also be utilized in the marine areas, either by a continuous projection of the geology known on land or by interpretation from indirect means such as marine geophysical surveying. Drilling and bottom diagonal sampling carried out routinely for the purpose of coverage, or selectively for the solving of problems, increases the store of geological knowledge. This data fund is enhanced by direct observations in manned submersibles and scuba diving, or with the use of remotely controlled devices such as unmanned submersibles equipped with television and camera. But all these direct methods are costly and time-consuming, and this is significant in an area covered by an ice canopy most of the year. Ship-board operations and the intelligent use of the ice platform will provide suitable bases for the programs to be mounted that will enable sufficient data to be obtained for the purpose of making judicious decisions on the use of the region.

Hydrographic surveying is a necessary adjunct to marine geology practices, particularly when designing landing areas for small sea craft, large port facilities, transport routes for Arctic shipping, anchorages, and sea-floor crossings.

The shipping industry is directly affected by the geology of an area, especially where rock structures prevent passage of vessels or construction of port facilities. Marine pipelines and cable lays are similarly affected, not only in the case of sea-floor crossings, but in landings

as well. Unconsolidated sediments may also offer some risk in that they are geotechnically unstable and unable to support any installation. This situation could arise in an area of intense current scour, and hence the installation could be undermined or buried. It could also arise in an area susceptible to submarine landslides where the installation or foundations could be torn from their footings, removed by mass flow, or buried by dislocated sediments. Geological and geophysical surveys can commonly indicate and delineate such potentially hazardous construction or utility areas, and should be undertaken before development of a coastal and marine area commences.

CURRENT SITUATION

Much of the geological history of Lancaster Sound is related to the geology of the entire archipelago. Early ideas on its origin stressed the concept of an inter-island geological unity (Fortier and Morley, 1956). Accordingly, ancient rivers of the Tertiary period had developed a trunk system over the entire land mass of the High Arctic, and these rivers had carried eroded sediments via the trunk system to the adjacent Arctic seas. Later, the river valleys were submerged to form the present seaways identified as the inter-island channels and adjacent inlets of the modern archipelago. But that is only a part of the late history of the archipelago generally, and of Lancaster Sound specifically.

Lancaster Sound owes its origin to the development of geological structure, in particular, a down-faulted block of the earth's crust (Kerr, 1979). Upon the surface of this block, itself down-faulted numerous times since 100 million years ago, rivers and later glaciers eroded the bedrock and sediments. These processes modified the existing valley systems to form characteristic U-shaped valleys, cliffed headlands, and valley spurs (Pelletier, 1966). Some marine erosion was taking place as the land was submerged beneath rising sea levels, perhaps many times during the past one to three million years. Inter-bedded layers of marine sediments and glacially deposited moraines are evidence of these natural processes. Following the retreat of the last great ice sheets that covered the area, the emergence of the land occurred as the final major event. This is seen in the raised beaches, now lying at elevations of several tens of metres, a height that was at sea level 10 000 years ago (Craig and Fyles, 1960).

Geological Framework

The oldest rocks of the region are Precambrian in age and occur mainly on the eastern portions of Devon and Baffin islands, on almost all of Bylot Island, and in the western portion of Somerset Island adjacent to Peel Sound (Map I.1; Figures 1,2). Granite and other crystalline rocks comprise the older (Archean) formations of the Precambrian sequence. The younger Precambrian rocks (Proterozoic) consist of limestone, dolomite, and well-stratified shales, siltstones, and sandstones.

Paleozoic rocks form the next youngest portion of the geological column, and consist of shales, quartz sandstones, evaporite deposits such as salt and gypsum, and limestones, some of which are abundantly fossiliferous (Figures 3,4). These rocks are found in the northern part of Borden Peninsula, and comprise the bedrock of the islands around Lancaster Sound almost totally.

The youngest rocks in the area are siltstones and sandstones of late Cretaceous to early Tertiary Age. They occur in minor abundance in outcrops along structural troughs (grabens) in the western parts of Devon, Cornwallis, and Somerset islands. Their major occurrence on land is in the southwestern corner of Bylot Island, and due south across Eclipse Sound in the northeastern part of Baffin Island. At sea, seismic investigations have revealed a great thickness of these rocks (about 4 000 m) beneath the floor of Lancaster Sound.

Both geological and marine seismic profiles show that Lancaster Sound is a down-dropped block of the earth's crust, with very high-angle fault walls on its northern and southern boundaries (Figure 5). The seismic records also reveal subsequent block faulting in the area so that the main graben beneath Lancaster Sound is itself cut by subsequent and similar faulting. Some of this faulting has extended northerly and southerly from Lancaster Sound to form other channels of the Arctic Archipelago as well as adjacent bays and inlets, such as Maxwell Bay. This faulting also produced the grabens containing Tertiary sediments on the nearby islands (Map I. 1). Because late Cretaceous and early Tertiary rocks are involved in the faulting, it is felt that dislocations formed no earlier than late Cretaceous times and continued through to the Tertiary period. This movement originated from global forces acting on huge plates of the earth's crust located in Baffin Bay and as far distant as the mid-Atlantic area.

As a result of these stresses and the subsequent post-Tertiary geomorphic processes, the angular directional relationships of the channels and many adjacent inlets and bays of the Arctic Archipelago were produced.

Physiography

The physiography and its causative processes are sufficiently distinct in the land area from that below sea level that both can be described separately. Because sea, land, and air meet uniquely at the coastline the processes affecting the geomorphology of the beach are also dealt with separately.

The Land

Several divisions have been devised to describe the physiographic region of the Arctic Islands (Map I. 3) (Bostock, 1970). Generally these divisions tend to reflect the nature of the underlying bedrock. Davis Highlands in the eastern parts of Devon, Bylot, and Baffin islands are underlain by rocks of the Archean Age (Figures 1, 2, 3). They comprise mountainous topography, with accordant peaks reaching a summit level of 1 500 m above sea level. Much of the country in the highlands is covered by large local icecaps. Along the coast, numerous fiords dissect deeply into the islands' interiors, and some reach down to several hundreds of metres below sea level. Adjacent to the Davis Highlands lies the region of the Baffin Uplands. This is a plateau area that comprises Proterozoic rocks mainly, and is less dissected than the Davis Highlands. Its gentler relief has a summit of 1 000 m above sea level, and occupies only a small part of the study area in the southeast.

Lancaster Plateau is the major physiographic feature of the Lancaster Sound area occurring on land. It is 300 to 700 m in elevation on Devon Island, Somerset Island, and the Brodeur Peninsula. Its general uniformity is due to the occurrence of flat-lying and gently dipping Paleozoic strata that underlie the plateau in its entirety. Upon these rocks, terrestrial erosion together with the influence of structural forces has produced a remarkable series of cliffs that are familiar features of the landscape around Lancaster Sound. The butte-and-mesa-like features of Caswall Tower and Prince Leopold Island are results of these natural processes (Figure 4). Further south, the Lancaster Plateau merges with the Boothia Plain, also underlain by Paleozoic

Figure 1 Inugsuin Fiord, east coast of Baffin Island; cliffs rise more than 1 300 metres from the fiord and are topped by small ice caps.

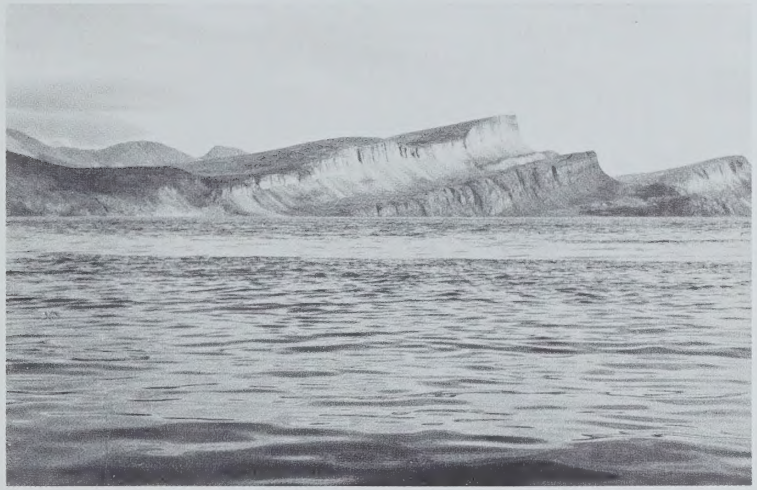


Figure 2 Block faulting along the shore of Adams Sound, northern Baffin Island. Precambrian granitic rocks that outcrop at sea level are overlain by basalt flows and white quartzites of late Precambrian age. G.S.C. Photo 142431.

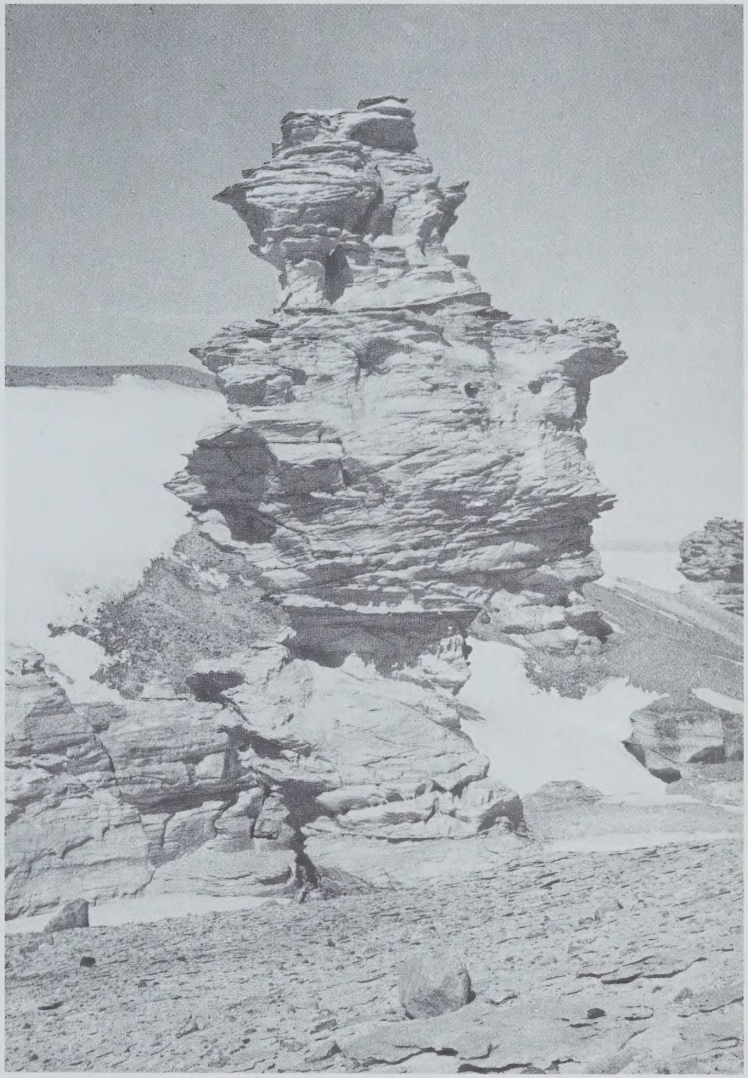


Figure 3 Hoodoos in Gallery Formation (early Paleozoic age); Arctic Bay, Baffin Island. G.S.C. Photo 201937.

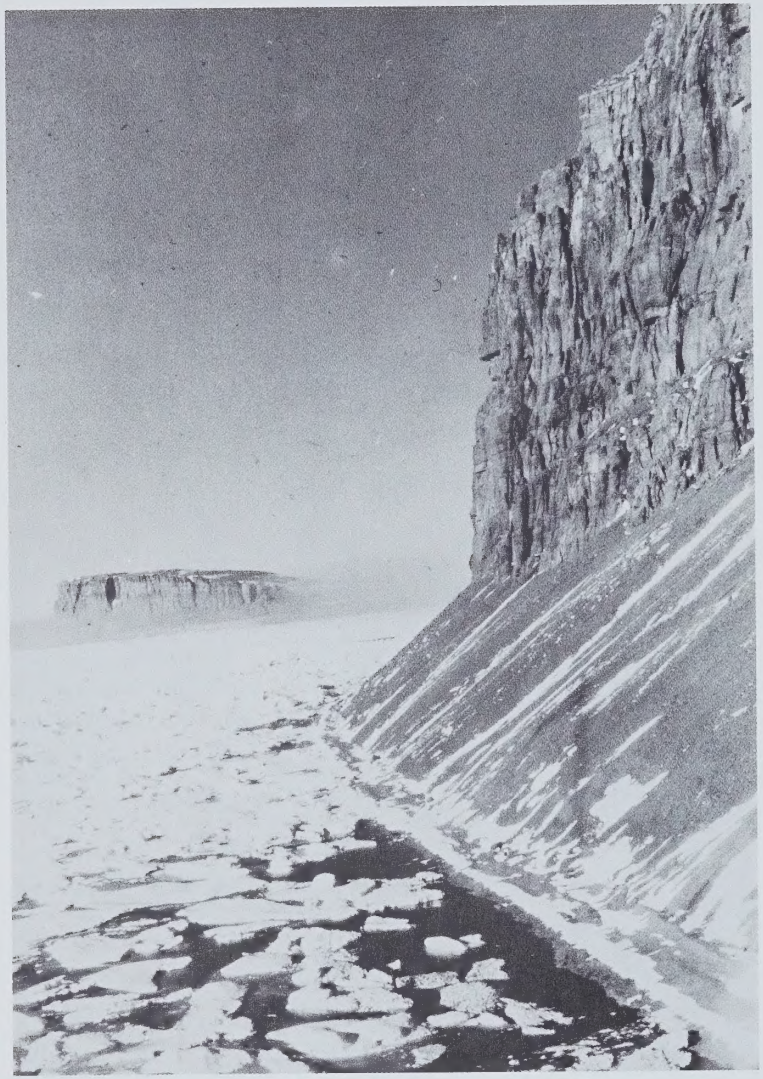


Figure 4 Pressure Point and Limestone Island in background. Talus and cliffs composed of Paleozoic limestone, Lancaster Sound. G.S.C. Photo No. 203419-Q, R.B. Taylor Aug. 31, 1979.

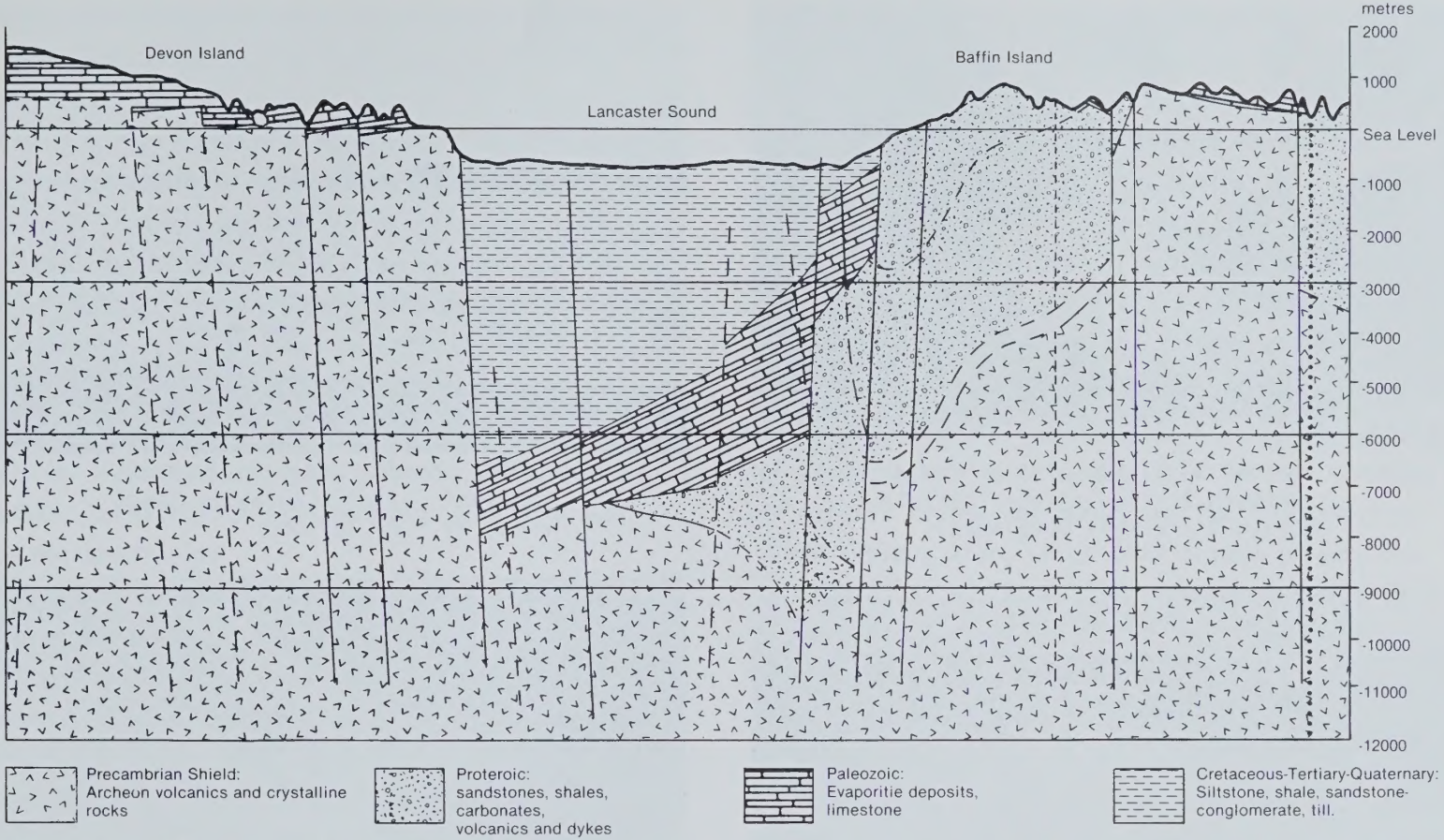


Figure 5 Geological cross-section of Lancaster Sound between southern Devon Island and northern Borden Peninsula, Baffin Island (from J.W.Kerr, 1979)

Figure 6 Glacier west side of Navy Board Inlet, northern Baffin Island; lateral moraines are well developed.

Figure 7 Lateral moraines in valley incised into Lancaster Plateau, northern Baffin Island. N.W.T.

Figure 8 Mobile sea ice along the shore of Somerset Island, Lancaster Sound. Photo by R.B. Taylor.

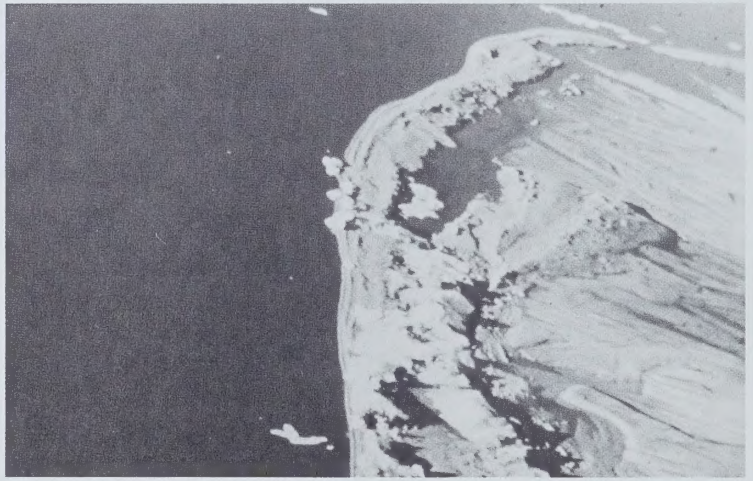


Figure 9 Ice-push ridges and ridged ice occurring across the coastal zone, Somerset Island. Photo No. 2053587-V, R.B. Taylor.

limestone, sandstone, and shale, and falls gently toward sea level in the vicinity of the Gulf of Boothia.

The Parry Plateau region lies immediately west of the Lancaster Plateau, north of Lancaster Sound. It includes both Cornwallis and Little Cornwallis islands, and in the eastern portion is also underlain by Paleozoic strata. Generally, the summit level is less than 230 m but the topography, similar to that of Lancaster Plateau, gives way in the west to the pronounced ridge system of Bathurst Island. These ridges have summit levels of 270 m, and trend almost easterly to northeasterly.

Boothia Plateau, in the southwestern part of the study region, is underlain by crystalline rocks that occur as a northerly trending extension of the Canadian Shield. In the south, Boothia Plateau is nearly 800 m above sea level, but declines toward the adjacent lowlands in the north.

Numerous icecaps and valley glaciers (Figure 6) abound on Baffin, Bylot, and Devon islands. Deposits of till are common and, in the south, particularly on Baffin and Somerset islands, considerable evidence of former glaciers exists, as follows: glacial striae or grooves on bedrock indicate the direction of ice movement; hummocky terrain and moraines show where ice once stood before receding; old spillways on northwestern Somerset Island demonstrate the evidence of ancient ice and melt-water passages; and eskers and kames attest to the former occupation of the land by ice lobes or tongues extending from a nearby icecap.

The ploughing, plucking, and scraping actions of these glaciers are responsible for the carving of coastal fiords and modifying the pre-existing river valleys along which they flowed (Figure 7). In coastal areas these processes are taking place beneath the sea, as well as on land, much as they did during the Pleistocene Epoch.

Mostly the drainage pattern on land is dendritic, except in areas of strong structural control where it becomes trellis (Map 1.8). These patterns were inherited from an early Tertiary river system, modified by glaciation, and controlled partly by structures that developed late in the Mesozoic Era and early in the Tertiary period.

The Coastal Area

The northern coast of Lancaster Sound (mostly Devon Island) forms a smooth curve, broken by fiords and bays flanked by nearly continuous coastal cliffs rising to 600 m above sea level. These cliffs are usually fronted by talus deposits or narrow gravel beaches that protect the rock face from active erosion by waves or sea ice. In areas where coastal slopes are low (Maps I.4, I.5, I.6) flights of raised gravel beaches have formed. At the entrance to Croker Bay, gravel beaches extend as much as 4 km inland across a low coastal plain. Where glaciers do not reach the sea, bay-head deltas occur in the fiords of Devon Island. Tidewater glaciers are only found east of Cape Warrender, at Croker Bay, Cuming Inlet, and Blanley Bay (Maps I.4, I.5, I.6) (Barrie et al, 1978).

The southern shore of Lancaster Sound is made up of Baffin and Bylot islands. Precipitous cliffs that rise to 490 m occur along Brodeur Peninsula. A lower coast, with well-developed raised beach terraces, and several large deltas are found along Borden Peninsula. Although the northwest corner of Bylot Island is low, the remainder of the northern coast rises sharply from the sea to elevations of 600 m generally, and some to over 1 200 m. This highland is mostly ice-covered and is occupied by numerous valley glaciers that flow toward Lancaster Sound.

The coast of Lancaster Sound is underlain by sedimentary rocks, mainly of relatively unresistant, horizontally bedded limestones of Paleozoic Age, except for the east end of Devon and Bylot islands where Precambrian rocks occur. Erosion of the cliffs is primarily the result of frost action. Although the bedrock is not resistant, rates of erosion and littoral sediment transport are low because the low-energy waves are unable to redistribute the coarse sediments. However, high-energy waves, with a long fetch, and some that have developed during storms may produce considerable destruction along the coast. All erosion caused by waves takes place during the short open-water periods that are characteristic of Lancaster Sound.

Evidence from secondary information indicates the beach sediments of northern Lancaster Sound are pebble to cobble size, somewhat similar to sediments found along Barrow Strait. Mixed sand and gravel beaches occur along Borden Peninsula, and rocky shores are common along northern Bylot Island.

The Arctic islands are a low-energy wave environment. However, because of the proximity to Baffin Bay, wave fetch and open-water season are

longer at the eastern entrance to Lancaster Sound. Therefore, sediments on the shores of eastern Lancaster Sound are subject to greater reworking by waves than those on the shores further north or west within the archipelago.

In Lancaster Sound sea ice may never consolidate and freeze solid during the winter, so breakup can occur as early as March or April (Lindsay, 1969). Despite the early removal of offshore ice, shore-fast ice clings to the coast and in the bays until June or July. Beaches are not reworked by waves until both sea ice and shore-fast ice have disappeared. The icefoot, a form of shore-fast ice built across the beach, varies in thickness and width but the thickness generally approximates the tidal range. Once waves begin to erode the shore-fast ice, it melts quickly. Therefore melting begins first in eastern Lancaster Sound and progresses westwards. The bays and fiords of southern Devon Island become ice-free between late June and late July, depending on the occurrence of favourable northerly winds that blow the ice into Lancaster Sound. Ice begins to reform in the coastal zone in September, so freezeup follows a reverse pattern to that of breakup, with fast ice covering the bays of western Lancaster Sound first and then the bays farther east. Open-water season, the period when waves rework the beach, is therefore three to four months.

In August, southeast and northwest winds prevail at Dundas Harbour on eastern Devon Island (Canadian Hydrographic Service, 1970). Therefore both shores of Lancaster Sound experience considerable onshore winds. The magnitude and frequency of storms, hence beach change, depend on the number of occasions when open water coincides with strong onshore winds. Between 1972 and 1976, the only season when open water in Barrow Strait prevailed long enough for several sets of storm waves to rework the beaches was during 1974. The shores of Lancaster Sound are also thought to experience variable rates of annual beach change.

Mean tidal range varies from 1.7 to 1.8 m in Lancaster Sound, with spring ranges of 2.8 to 2.87 m (Canadian Hydrographic Service, 1976). The tidal range is greatest in the east and decreases progressively toward Barrow Strait in the west.

Ice floes (Figure 8) and brash ice are often transported ashore during storms. The brash ice is generally carried up the beach slope (Figure 9) and deposited, and sometimes buried, on the upper foreshore or backshore. The beaches of Barrow Strait are subject to overwash when open water and

strong onshore winds coincide with spring tides. Brash ice and beach sediments are deposited well above normal limit of wave action and considerable changes in beach profile take place.

The amount of beach sediment available for reworking by waves during any one storm is a function of the thickness of the active layer. The beaches of Lancaster Sound are underlain by permafrost, which thaws each year to a depth rarely exceeding one metre. In spring, the active layer thaws fastest at the top of the beach and thaws progressively across the foreshore slope as the fast ice melts and waves begin to strike the beach. The maximum thickness of the active layer across the lower foreshore occurs in late August or early September. In the fall, as air temperatures drop below freezing, the thickness of the active layer decreases rapidly across the backshore and beach berm, but the sea has a more moderating influence on the lower foreshore where freezing occurs later.

Along the beaches of northern Somerset Island longshore transport of sediments occurs over short distances. This transport commonly occurs back and forth along the shore, i.e. from east to west, because of the variable direction of the waves striking the beach.

Throughout Lancaster Sound ice plays an important role in littoral processes. Apart from preventing waves from reaching the beach, sea ice also causes changes when it is rafted onshore or forced into ridges across the nearshore (Figure 9). Sea ice frequently impinges on the shores, causing ice-push ridges, some of which occur as much as 185 m inland on Somerset Island (Taylor, 1976).

The Marine Area

In the marine portion of Lancaster Sound, the geology and physiography are known from the results of bottom sampling and seismic and hydrographic surveys. Figure 5 clearly shows the down-faulted block that forms the structural trough underlying Lancaster Sound; it also shows the amount of vertical displacement of the geological formations - 8 000 m on the north side and several hundred metres on the south.

Exaggerated bathymetric profiles shown in Figure 10 demonstrate the steep flanks of the sound and the generally featureless central portion. This floor has been eroded by ancient Tertiary rivers and later modified by the passage and occupation of Pleistocene glaciers or ice shelves.

In addition to the modifications and disturbances of the sea bed produced by ice tongues, the keels of drifting ice from floes, pressure ridges, and icebergs produce a ploughing and gouging action on the sea floor (Lewis et al, 1977; Pelletier, 1980). Most of this action takes place near shore in water depths of 50 m or less. But deep-draught keels of icebergs, some 300 to 500 m in overall height from keel to summit, may produce scour marks in water depths of 400 m. It is possible that some marks are deeper, but they may be ancient; indeed, even some shallower scouring may be several hundreds to a few thousands of years old. Mostly the ice-gouged grooves are several metres (2-10) deep and are bounded by parallel levees of ice-pushed and ice-squeezed sediments along the flanks of the scour. In the coarser sediments such as sands and gravels, the action of the drift ice tends to be a ploughing phenomenon; in the fine muds (silt and clay), the action tends to be hydraulic. Not all ice-scour features are modern. Some are infilled with sediments and, together with their associated levees, show a subdued relief in profile. Some scours may be overgrown with biota, although this may not suggest great antiquity beyond several years or decades at the most. An examination of the seismic profiles of these features may help to determine their relative age, but radiometric dating techniques on the sediments as well as on their contained fauna and flora is required for absolute dating.

Other evidence of physiographic processes is present in the coastal inlets and fiords. These features have been localized by fault structures along which river and ice tongues eroded ancient valley floors leading to the original fluvial trunk. Characteristic of some of these inlets is a physiographic sill that separates bodies of deeper water in the headward portions from the deeper water of Lancaster Sound (Map I.3). These sills may be a terminal moraine, which is typical of deposits originating from valley glaciers. The hummocky topographic profile along the longitudinal axis of these inlets is also typical of fiords, particularly the basinal aspect at the valley head and the higher elevation at the terminal end of the glacier course. Finally, the sills actually overhang Lancaster Sound, and probably represent the so-called hanging tributaries that are characteristic of glacially

scoured highlands. Because these features are underwater, but were formerly above sea level, they are evidence of a regional vertical movement of the land relative to the sea bed. This evidence, together with the presence of raised beaches that have been dated, suggests that the most recent emergence of the region began about 10 000 years ago. No adequate evidence is available to confirm the timing of similar vertical movements involving emergence and submergence for other times in the Pleistocene Ice Age.

Bottom Sediments

In accordance with the physiographic development of the Lancaster Sound region, it is expected that river deposits would form part of the unconsolidated sediments that represent the latest portion of the geological record in the area. Seismic profiling records indicate the presence of marine and glacially derived sediments, but coring is required to confirm the real nature of any sediment type. To date, the cores have not penetrated sufficiently in these areas to reveal former river beds. Modern bottom sediments (Map I.7) are predominantly ice-rafted and marine in origin, although a substantial amount is derived from rivers and eroded coastal deposits.

In the western part of Lancaster Sound, ice deposited considerable amounts of till - a mixture of boulders, pebbles, sand, silt, and clay. With the retreat of the ice and subsequent submergence as the sea level rose, marine sediments were deposited over the floor of Lancaster Sound. Beneath Barrow Strait, currents scouring the sea bottom eroded the finer sediments and left a coarse lag of boulders and sand, and patches of silt, clay, and mixtures of both. The eroded sediments were transported easterly by marine currents, and formed a deposit of finer sediments at least 30 m deep east of Barrow Strait. These deposits increase in thickness to 200 m or more at the mouth of Lancaster Sound, where they comprise clay and silt, and merge without interruption into similar sediment types in Baffin Bay. Along the northern and southern coasts of Lancaster Sound, and indeed in the entire coastal zone of the islands, deposits generally consist of coarse sediments such as cobbles and boulders. In certain areas, such as that south of Radstock Bay, glacial deposits in 350 m of water show evidence

of current scour (Lewis et al, 1977). Further west, on the sea bottom of Barrow Strait and Peel Sound, the occurrence of gravels and the photographic observations of bending floral, crinoidal, and anemone stalks are all evidence of substantial bottom currents (Figures 11, 12).

Most inlets and fiords contain coarse sediments such as boulders and cobbles in thin beds along their coasts, but have considerably thicker deposits of fine sands, silts, and clays in their central basins. These latter form layers that are generally undisturbed, although evidence exists of slumping and turbidity flows originating from the steep fiord walls such as those in Strathcona Sound. Commonly, lobes of coarser sediments project from the inlets into Lancaster Sound, which may alter the regular sedimentary pattern of the sound.

Seismicity

Two zones of earthquake epicentres (Map 1.2) are most prominent in the Lancaster Sound region. One occurs in the Barrow Strait area and is associated with geological structures to the south. The other earthquake zone occurs at the mouth of Lancaster Sound and is related to seismic activity originating in Baffin Bay. The danger of such activity lies in the activation of submarine landslides, particularly in the narrow, steep, sediment-laden fiords. Strathcona Sound is an example of an area facing this hazard.

Sub-sea Permafrost

Within the unconsolidated sediments, seismic velocities indicate the presence of frozen gas hydrates, or perhaps ice-bonded sediments, which is characteristic of permafrost.

RECOMMENDATION OF LAND USE

Beaches

Many beaches are suitable for landing watercraft and aircraft, and may be used to build shore facilities for communal sites or staging areas. However, beaches fronting cliffs, although offering some haven for small watercraft, may be unsuitable because no land access to them exists. Aggregates for construction are commonly found on beaches, which may provide an economy in transport and supply. Some coastal areas may offer safe shelter because of shoals at the approaches that

arrest the movement of threatening sea ice.

Harbours

Several inlets are suitable for harbours but protection from drifting sea ice must be considered. The local sea bed should also be examined for geotechnical properties in order to assess the feasibility of port construction. Some of the factors governing selection of sites for marine terminals are given in Table 1, which is adapted from a Department of Transport study on the subject carried out by field officers of the Geological Survey of Canada. In the geological context, the main uses centre on the beaches, fresh water supply, inlets and their dual requirement of suitable water depth and adequate shelter from moving sea ice, bedrock, aggregates for construction and engineering purposes, and the nature and stability of the adjacent sea bed.

Seabed

Hazards such as ice scouring nearshore, shoals, current action, slumping, and sea-bed materials, whether bedrock or sediment, must be considered carefully in regard to uses of the sea bed.

Pipeline and cable laying are two significant applications of sea-bed engineering. The former, particularly, may offer a viable alternative to shipping in the inter-island area, especially in the matter of transporting natural gas and petroleum. But both undersea carriers could be affected by ice scouring across the sea floor.

Drilling for natural resources demands a knowledge of the sea bed, because it could well be a major operation in the Lancaster Sound region. Although no offshore mining exists in North America, in a decade or so it may become an operation in the Arctic region as an extension to the present mining on land.

COMPLETENESS AND QUALITY OF DATA

On a broad scale, sufficient geological data are accessible to give a reasonable idea of the geology of the Arctic Islands. Considerable detail has been amplified by field geologists so that exploration on surficial aggregates, bedrock, and ore deposits can proceed without undue interruption of activity due to lack of information. The same is not true for the marine areas. Along the coast only a small percentage of

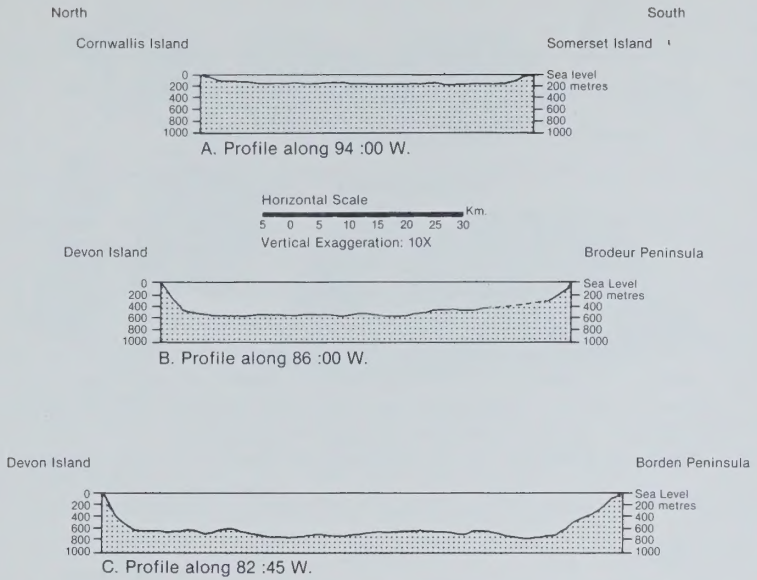


Figure 10 Bathymetric profiles across Lancaster Sound. All views look east from Barrow Strait to Baffin Bay (from Canadian Hydrographic Service; Natural Resources Maps 26130, 26140, 26145, 26240).

Figure 11 Stalks of crinoids being bent under pressure of bottom currents in western Lancaster Sound and adjacent Barrow Strait in 100-150 m depth. Note the pebble-cobble pavement and the absence of finer sediments, due also to the influence of moderate to strong bottom currents.

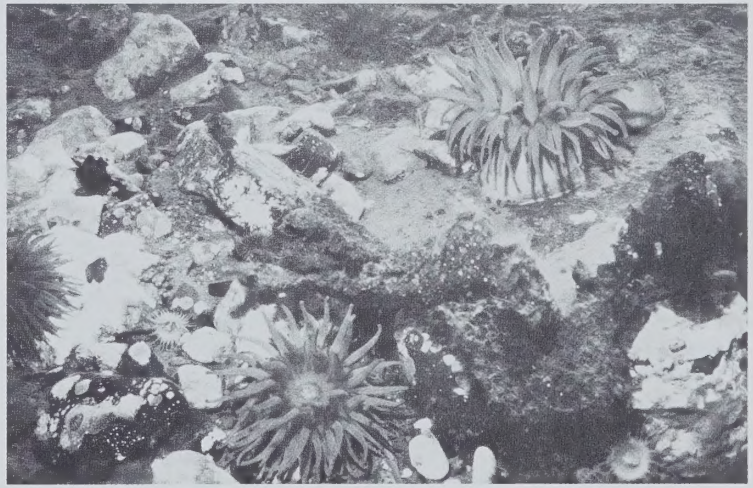


Figure 12 Sea anemones and corals encrusting rocks in Strathcona Sound in 20 m depth. G.S.C. Photo No. 203419-M by P. McLaren.

Table 1
Potential Marine Terminal Sites, Listed According to Island*

Potential Marine Terminal	Bathymetric Information	Accessibility	Shelter	Anchorage (based on water depth)	Length of Open-Water Season (estimated in days)	Landing Beaches	Availability of Construction Materials	Potential Airstrip	Fresh Water Supply	Additional Comments
Devon Island										
1. Radstock Bay	Excellent	Excellent	Excellent	Good	80	Excellent	Excellent	Excellent	Excellent	Poor anchorage in northern part of bay
2. Maxwell Bay	Excellent	Excellent	Poor	Poor	85	Good	Good	Poor	Poor	
3. Croker Bay	Good	Excellent	Poor	Poor	129	Good	Good	Excellent	Good	Calving glaciers
4. Dundas Harbour	Excellent	Good	Limited	Good	129	Good	Good	Limited	Poor	Once used as an RCMP post
Baffin Island										
5. Arctic Bay	Excellent	Good	-	Good	-	Excellent	Good	Limited	Good	Inuit settlement
Somerset Island										
6. Aston Bay	None	Good	Poor	-	-	Good	Excellent	Poor	Good	Some years bay remains ice covered
Prince of Wales Island										
7. Baring Channel	Limited	Good	Limited	-	-	Good	Excellent	Good	Good	Possible site also on south Russell Island
8. Back Bay	None	Good	Good	-	-	Good	Good	Good	Good	-

*Locations are shown in Figure 14.
Taken from Barrie et al., 1978.

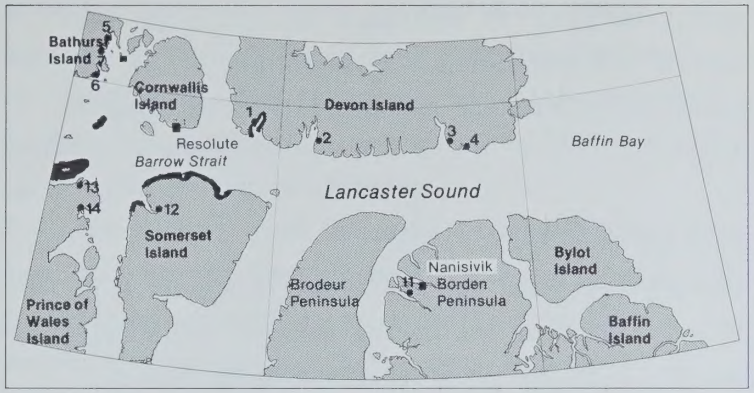


Figure 13 Potential marine terminal sites in the Lancaster Sound region. (See Table 1, adapted from Barrie et al, 1978)

a few islands has been mapped in the detail required to understand processes, or recommend proper, if not optional, use of the beaches and coastal zone in general. But field studies have been augmented by analyses of air photographs, thus widening the scope of completed coastal programs as well as those underway.

Offshore, the geological information in the realm of the public sector is meagre, although the proprietary geophysical and geological data made available to the Department of Indian Affairs and Northern Development appears to be sufficient to justify exploration and development of oil, gas, minerals, and aggregates. The Geological Survey of Canada has not surveyed the area sufficiently to draw a reasonable geological map. However, with the quality and coverage of the geophysical data on hand it is possible to construct a framework of the marine geology in the Lancaster Sound region. Bottom-sampling coverage is incomplete everywhere except for very broad-scale maps. For the present scale (1:1 000 000) it is not possible to extrapolate a known sediment pattern to an unsampled area. In certain areas such as deep water, the bottom sampling is sufficient, but in shallower coastal zones the control is inadequate. Nevertheless it is possible to show the major generalities (Map I.7).

NEED FOR ADDITIONAL STUDY

The greatest need for additional study is a fuller understanding of the marine geology in Lancaster Sound. Although proprietary information may provide insight, it is unavailable to the public sector and therefore the publishable research must be carried out by government agencies and the universities. The latter need special support and funding for this work so the burden of such surveying and problem-solving must fall on government scientists. In this regard, the Earth Physics Branch and the Geological Survey of Canada are the chief investigators. Also needed are additional bathymetric maps drawn at a scale of 1:250 000, except in coastal areas and inlets where more detail is required. The Canadian Hydrographic Service, Department of Fisheries and Oceans, is the single agency in Canada responsible for this work, and is attempting to complete the mapping coverage in areas of intense economic and

shipping interest. More refined maps should outline sea-bed features to a practical degree, not only to aid the transport facilities but to assist the geotechnical engineers in their efforts to circumvent natural hazards.

The type of work required is mostly seismic and involves delineating geological formations and structures, as well as an understanding of the nature of the unconsolidated beds lying beneath the sea floor. This knowledge is essential for engineering work because of possible hazards, but it is also needed in order to expand our knowledge of the natural history of the region. It is this knowledge that is of greatest importance in dealing with problems of the protection of the environment, not to mention the search for our natural resources and their ultimate development.

Sea-bed sampling is insufficient regarding the search for aggregates. It should be undertaken in the shallower coastal areas, but some seismic surveys indicate that depths of 350 m may not be ruled out, particularly if construction aggregates are sought. At present only a very generalized map (Map I.7) can be drawn, showing the distribution of the main types of bottom sediments.

More thermal studies are required in order to understand the distribution of possible permafrost and frozen gas hydrates in the sedimentary beds beneath the sea floor. Seismic refraction techniques and thermal-sensing probes are the major tools in use, but their employment must be expanded considerably in Lancaster Sound if not everywhere in the Arctic.

Shallow bedrock drilling has not taken place in Lancaster Sound but this program would add to our geophysical and geological knowledge and thus give a better control of the geological framework than we presently hold.

RELATIONSHIP WITH OTHER SUBJECT AREAS

Because of the broad nature and multi-disciplinary scope of geological investigations, many other fields are influenced by its understanding. Throughout this report, details of these inter-relationships have been mentioned. The following is a summary of the areas influenced by geological investigations:

(i) shipping routes
(ii) construction industry
(iii) geotechnical engineering
(iv) exploration and development of natural resources
(v) community sites
(vi) staging sites for development work
(vii) locating airstrips
(viii) locating harbour sites
(ix) locating landing sites for small seacraft
(x) providing a base for vegetation map
(xi) selecting pipeline routes and routes for cable lay
(xii) selecting areas for erecting industrial and cultural installations
(xiii) providing information on natural hazards to industry and communities

Acknowledgements

The writer is indebted to many of his co-workers in the Geological Survey of Canada for the many contributions in field work and publications concerning Arctic Canada over the past two decades. The section on the geological framework was based largely on the works and compilations of R.J.W. Douglas, R.G. Blackadar, B.G. Craig, J.G. Fyles, Y.O. Fortier, H.S. Bostock, and J.W. Kerr. On the coastal zone, the contributions were by W.B. Barrie, R.G. Jubb, P. McLaren, and R.B. Taylor, and the glacial history by D.R. Grant, V. Rampton, and V.K. Prest. Much of the marine geology was from work by C.F.M. Lewis, S.M. Blasco, B.D. Bornhold, and D.E. Buckley. Hydrographic contributions were made by officers of the Canadian Hydrographic Service, and those in oceanography by A.R. Milne, B.D. Smiley, and R. Herlinveaux of the Department of Fisheries and Oceans at Patricia Bay, Sidney, BC. Such federal institutions as the Polar Continental Shelf Project (DEMR), the Defence Research Establishment Pacific, and the icebreaker fleet of the Department of Transport aided in material, logistic, and scientific support. Their help is gratefully acknowledged.

REFERENCES

Barrie, W.B., Bornhold, B.D., Hodgson, D.A., Jubb, R.G., McLaren, P., and Taylor, R.B. 1978. Coastal Reconnaissance for marine terminal planning in the high Arctic. Geological Survey of Canada, Open File Report No. 633, Ottawa.

Bostock, H.S. 1970. Physiographic Subdivisions of Canada. in Geology and Economic Minerals of Canada, (ed.) R.J.W. Douglas. Geological Survey of Canada, Economic Geology Report no. 1, Chapter C, pp. 11-31, Ottawa.

Canadian Hydrographic Service. 1970. Pilot of Arctic Canada. Vol. 1, Fisheries and Marine Service, Environment Canada, Ottawa, 247 p.

_____. 1976. Tide and Current Tables. Vol. 4, Fisheries and Marine Service, Environment Canada, Ottawa, 59 p.

Craig, B.G., and Fyles, J.G. 1960. Pleistocene geology of Arctic Canada. Geological Survey of Canada, Paper 60-10, Ottawa, 21 p.

Fortier, Y.O., and Morley, L.W. 1956. Geological unity of the Arctic Islands. Royal Society of Canada, Transactions, Vol. 50, Ser. III, pp. 3-12.

Kerr, J.W. 1979. Structural framework of Lancaster Alaucogen, Arctic Canada. Geological Survey of Canada, Open File Report No. 619, Ottawa.

Lewis, C.F.M., Blasco, S.M., Bornhold, B.D., Hunter, J.A.M., Judge, A.S., Kerr, J.W., McLaren, P., and Pelletier, B.R. 1977. Marine geological and geophysical activities in Lancaster Sound and adjacent fiords. Geological Survey of Canada, Paper 77-1A, pp. 495-506, Ottawa.

Lindsay, D.G. 1969. Ice Distribution in the Queen Elizabeth Islands. Ice Seminar, Petroleum Society of Canada, Institute of Mining and Metallurgy, and American Petroleum Institute, Calgary, May 6-7, 1968. Special Vol. 10, Canadian Institute of Mining and Metallurgy, pp. 45-60.

Pelletier, B.R. 1966. Development of submarine physiography in the Canadian Arctic and its relation to crustal movements. In Symposium on Continental Drift, (ed.) G.V. Garland, Royal Society of Canada, Special Publications No. 9, pp. 77-101.

_____. (1980). Review of surficial geology and engineering hazards in the Canadian offshore. Proceedings of the First Canadian Conference on Marine Geotechnical Engineering, Calgary, April 1979.

Taylor, R.B. 1976. Sea Ice Ridges, Somerset Island. ICE, No. 50, p. 13, Abstract.

Climate

by J.B. Maxwell

INTRODUCTION

The following report is a summary of data relating to the climate of Lancaster Sound and is drawn from existing studies and analyses. It is composed of a brief outline of weather observations available for the area, a discussion of the climatic controls influencing it, and short summaries of a number of pertinent climatic elements. The report is supplemented by 13 maps and 28 smaller figures.

Meteorological Data

The most direct source of weather data for Barrow Strait-Lancaster Sound-northwestern Baffin Bay is the meteorological observations made by ships passing through those waters or engaged in scientific research on them. The existing record is composed of some 8 000 observations spread over the period from July to October and principally from the years 1947-1978. It should be noted that most of these data are concentrated in the months of August and September. These data have been grouped into three geographical areas and the data for each area summarized and attributed to marine grid points (#10, 11, and 12 from west to east).

The marine observations can be supplemented by weather data collected at Atmospheric Environmental Service (AES) coastal stations in the immediate area. Four such stations may be considered: Arctic Bay, Dundas Harbour, Pond Inlet, and Resolute A. Of these, Resolute is by far the most useful as the other locations suffer from significant local effects and in general have much less comprehensive observation programs.

Short-term miscellaneous coastal observations have been taken by non-AES personnel. In some instances, such data have been analysed and the results made available in the literature: Taylor (1977) on Cunningham Inlet, Hill et al. (1978) on Cape Charles Yorke and others, and Jakobsson (1979) on Hamilton Island.

Table 1 summarizes the main sources of meteorological data used:

Table 1

Observing Site	Latitude Longitude	Elevation (m)	Observational Period of Record	Nature of Observing Program
Marine Grid Area # 10	74°30' 94°00'	-	Primary 1947-72 Overall 1903-72	July to October only 1 902 observations in total
Marine Grid Area # 11	74°00' 85°00'	-	Primary 1947-78 Overall 1903-78	July to October only 3 700 observations in total
Marine Grid Area # 12	74°00' 75°00'	-	Primary 1947-78 Overall 1903-78	July to October only 1 097 observations in total
Arctic Bay	73°02' 85°09'	11	Sept. 1937-May 1966, also 1971	Less than 24 hourly observations per day Gaps in record.
Dundas Harbour	74°32' 82°23'	5	Sept. 1930-Aug. 1933 Oct. 1945-Aug. 1950	Eight-hourly observations. Gaps in record.
Pond Inlet	72°40' 78°00'	4	Oct. 1921-Nov. 1960	Six-hourly observations. Gaps in record.
Resolute A	74°43' 94°59'	64	Oct. 1947 - continuing	Hourly observations since 1962.

Climatic Controls

The climate of the Lancaster Sound area primarily depends on the character of the solar energy input, topography, weather systems, and the nature of immediate and adjacent surfaces.

Figure 1 illustrates the variation of daylight hours during the year with latitude. At 74°N latitude, that of Lancaster Sound, there is continuous daylight from early May until early August and continuous night from early November

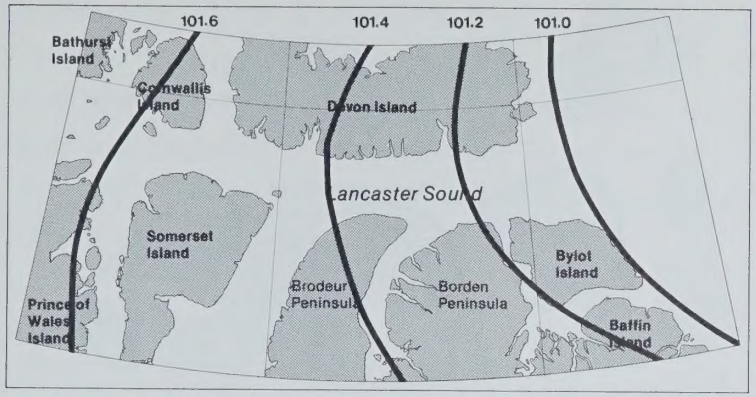
until the beginning of February. In summer, the amount of available solar energy is almost equivalent to that of temperate latitudes because the long days compensate for the small amount of solar energy received on any particular area at ground level. During the arctic night, however, no solar radiation is received. The lack of daylight in the winter is somewhat ameliorated by moon reflection on snow and ice so that some light is available to permit outdoor activity. An indication of the radiation regime may be gained from Figure 2 which shows measured global solar radiation and net radiation at Resolute. Global solar radiation reaches a maximum in June when almost 600 langleys/day are received. Maximum net radiation at Resolute occurs a month later when over 200 langleys/day are measured. Then, solar radiation received is still quite high and the reflectivity of the surface is greatly reduced, cutting down on the direct loss of solar radiation through reflection. There is a net loss of radiation during the period October through April inclusive.

Topography plays an important role in the Lancaster Sound area. To the south, Bylot Island and eastern Baffin Island are quite mountainous and partially glaciated, with elevations above sea level reaching into the 1 500 to 2 000 m range. The more westerly parts of northern Baffin Island, such as Borden and Brodeur peninsulas, are more plateau-like in nature with maximum elevations slightly in excess of 1 000 m on the former and near 600 on the latter. Across Prince Regent Inlet, Somerset Island is somewhat similar to Brodeur Peninsula. To the north, Devon Island gradually decreases in elevation from east to west. In the east, where it is glaciated, the maximum elevation is near 2 000 m, but to the west, heights are more in the order of 300 to 400 m. The southern coast of Devon is characterized by a number of narrow north-to-south-oriented inlets. In the extreme west of the area, Cornwallis Island has quite low elevations on its western half, but near 300 m in the east. The resulting influence of these generally high-elevation land masses surrounding Lancaster Sound is most pronounced on, for example, wind data collected in the area. It is most difficult to find a suitable land site at which to collect wind observations that are at all representative of the Lancaster Sound area. Arctic Bay, Dundas Harbour, and Pond Inlet are all markedly influenced by their local topography. Only Resolute offers a wind regime that is at all suitable and even it is

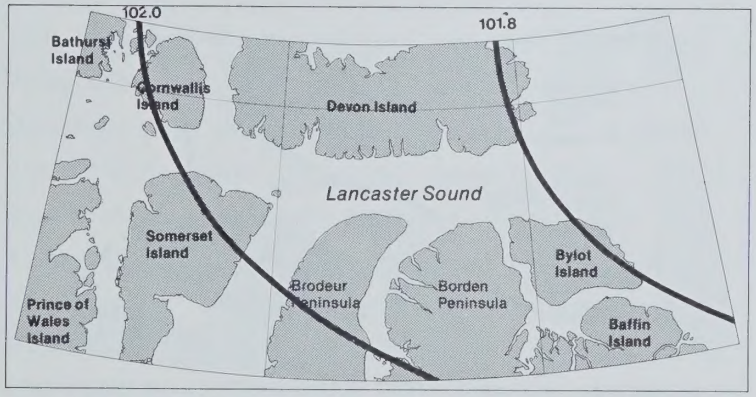
subject to some northwest-southeast channelling. Lancaster Sound itself is subject to marked west-east channelling of winds, as has been confirmed by the limited ship observations available.

Maps 1 to 4 show the mean sea-level pressure patterns during January, April, July, and October. Also indicated are the main cyclonic trajectories affecting the area. From the fall through the spring, Lancaster Sound is under the influence of an east-to-west pressure gradient, lying as it does between the intense Baffin Bay low-pressure centre to the east and an intense arctic high to the west. Most storms affecting the area move through Davis Strait into Baffin Bay where they frequently stagnate and increase in atmospheric pressure. In fact, most of the systems affecting Lancaster Sound are in the occluded stage as the Greenland icecap to the east restricts the supply of warm air to the lows, a supply that would be necessary to deepen or at least maintain the lows' intensity. Occasional systems tracking from the Keewatin over Baffin Island or from the west along Parry Channel also occur. In the summer, the pressure gradient across the entire Canadian Arctic Islands is very weak and a broad low-pressure area extends from Baffin Bay over eastern Lancaster Sound and northwards over Devon and Ellesmere islands.

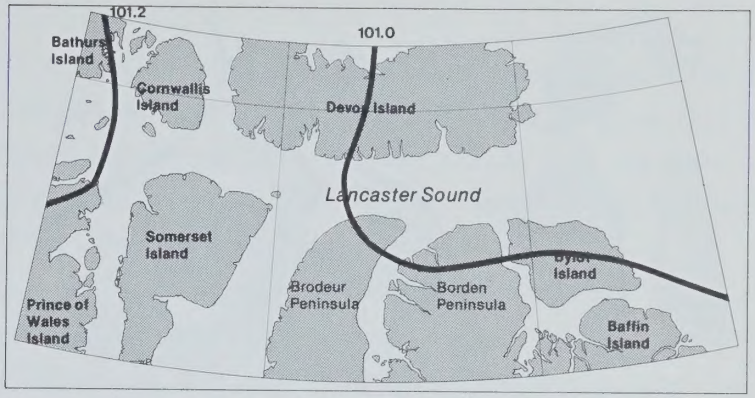
The most obvious surface characteristic of Lancaster Sound is the sea-ice cover which is present for much of the year. Lancaster Sound is an area where moving pack ice predominates during the winter, while some of the smaller waterways such as Pond, Navy Board, and Admiralty inlets are covered with fast ice from November until July. Tidal flux and wind stress keep the ice in broad waterways in motion throughout the winter although there is some variation in conditions in western Lancaster Sound and eastern Barrow Strait. These areas clear during July, but when adjacent waterways break up floes sometimes move in. Late August and early September is the most consistently open period of the year, but the end of September frequently finds the sound covered with new ice. Only on rare occasions are there still significant amounts of water past the second week of October. For adjacent land surfaces, the



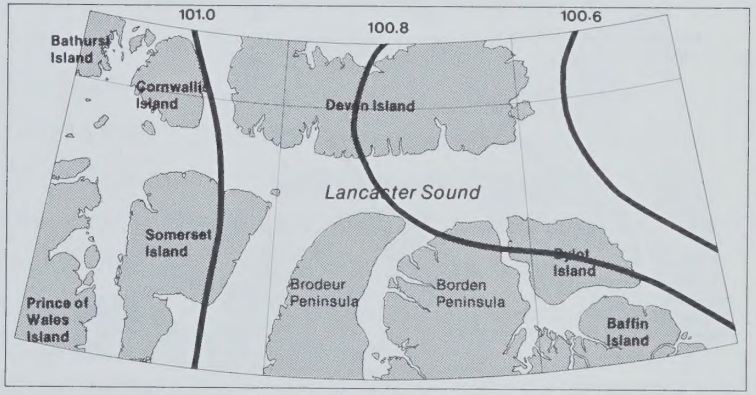
Map 1 January Mean Sealevel Pressure



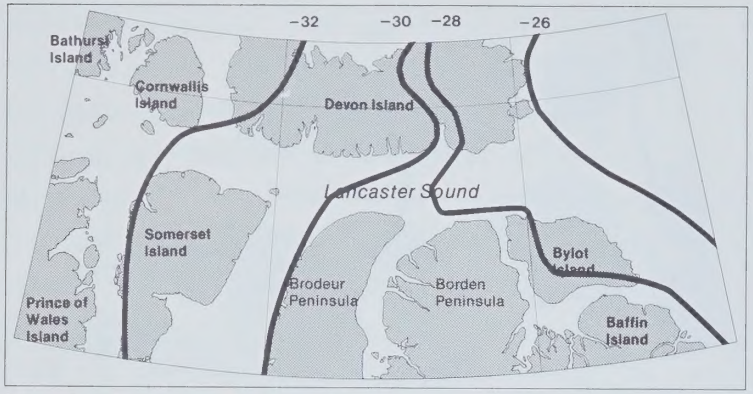
Map 2 April Mean Sealevel Pressure



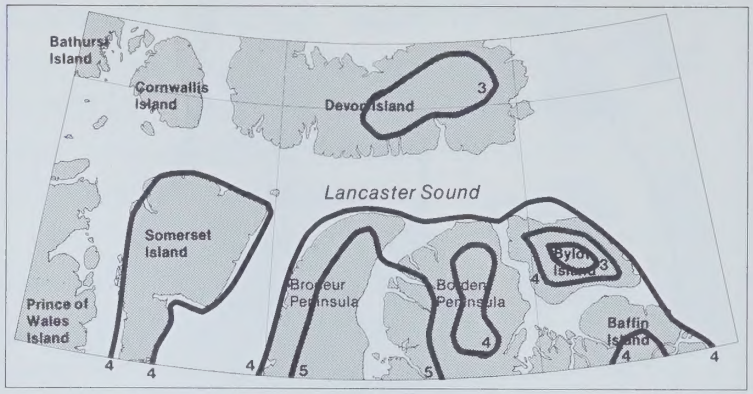
Map 3 July Mean Sealevel Pressure



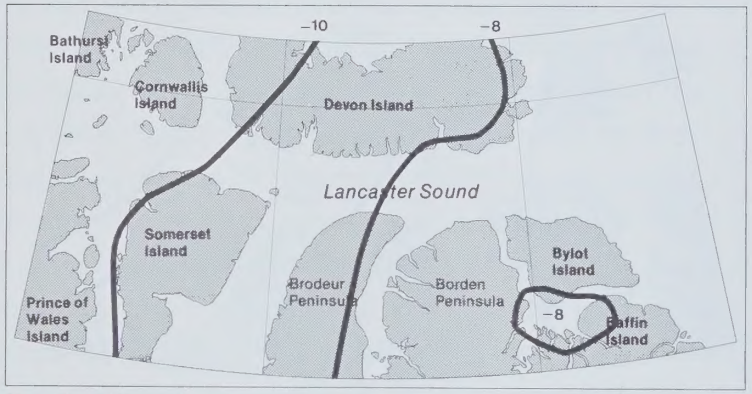
Map 4 October Mean Sealevel Pressure



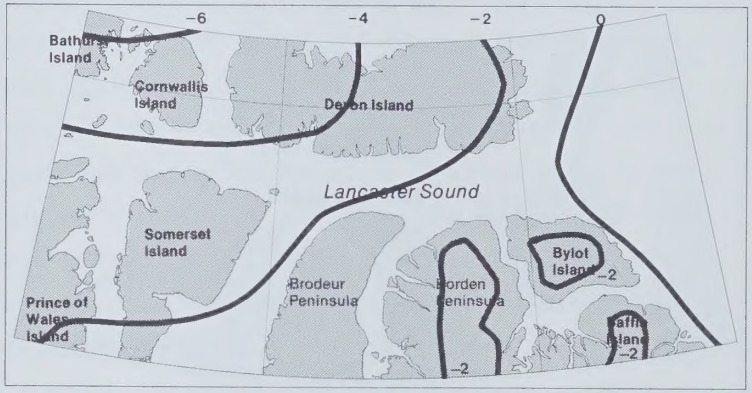
Map 5 January Temperature



Map 7 July Temperature



Map 6 May Temperature



Map 8 September Temperature

boundary of the snow cover, on average, remains south of Lancaster Sound throughout the year. Even the extreme northerly position of that boundary is south of the sound for 10 months of the year, from mid-September to mid-July inclusive (Berry and Scholefield, 1978).

CLIMATE ELEMENTS

Summaries are presented for each of the following nine climatic or related elements: air temperature, wind, wind chill, precipitation, structural icing (surface), aircraft icing, waves, ceilings and visibility, and air pollution potential.

Air Temperature (Maps 5 to 8, Figures 3 to 6)

Mean daily temperature maps (Maps 5 to 8) for January, May, July, and September (indicative of the four seasons) show that Lancaster Sound experiences an east-to-west gradient of temperature from the fall through the following spring, with the slope being most intense in winter when mean temperatures range from -24°C in the east to -32°C in the west. During the summer, the mean over-water temperatures lie in the 3°C to 4°C range with low-level land areas being a few degrees warmer. Along the north side of Lancaster Sound and Barrow Strait, the islands have not been analysed; however, spot values have been taken for Dundas Harbour and Resolute.

Monthly extreme maximum temperatures at the land stations are generally near +20°C in July, dropping to near 0°C in winter. Extreme minima range from about -5°C to -50°C from summer to winter. The limited marine data for temperature extremes for the August-to-October period suggest maxima a degree or so lower than at the land stations and minima several degrees higher, particularly by October. Figures 3 and 4 illustrate the observational data.

Percentage frequencies of occurrence of temperature classes are shown in Figure 5 for the various marine areas during the open-water season. The graphs generally follow what would be called expected trends. For example, in October, temperatures in classes below -11°C are progressively less frequent as one goes eastward from marine area # 10 in Barrow Strait to # 12 in

northwestern Baffin Bay, thus reflecting the mean-temperature pattern of the area. Figure 6 shows the corresponding trends at Resolute in addition to those for the other months of the year.

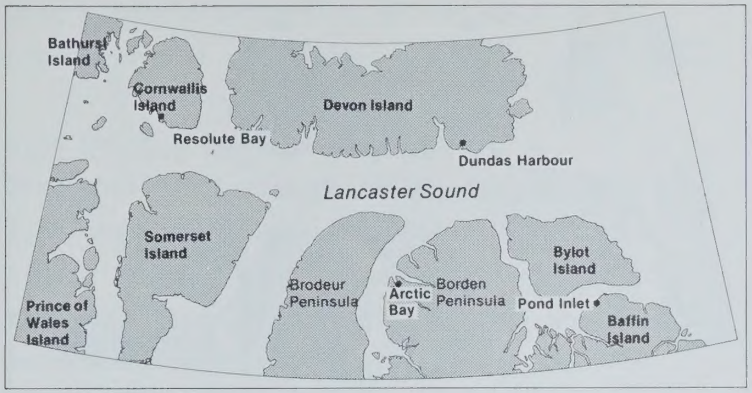
Wind (Maps 9 and 10, Figures 7 to 10)

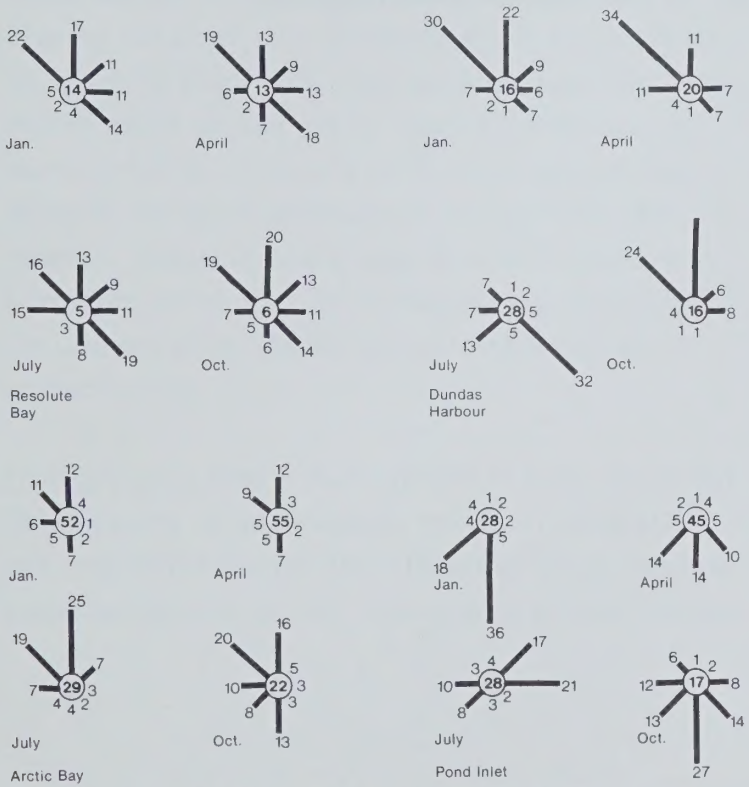
Wind directional frequency "roses" for the four land stations are shown in Map 9 for January, April, July, and October. Particularly to be noticed is the influence of local topography at the three more easterly locations; for example, the marked northwest-southeast channelling at Dundas Harbour and the high percentage of calms at Arctic Bay and Pond Inlet reflect the sheltered nature of the sites. At Resolute, there is a slight tendency for northwest-southeast channelling, but the directional regime is reasonably close to what would be expected from an examination of mean-pressure patterns.

During August and September, the height of the open-water season, roses are also available for the marine grid areas (Map 10). Two points may be noted here: one is the marked east-west channelling in Lancaster Sound itself as indicated at grid point # 11; the other is the reasonably good agreement between Resolute and the offshore roses at grid points # 10 and # 12. The unrepresentativeness of the three eastern land stations is readily apparent.

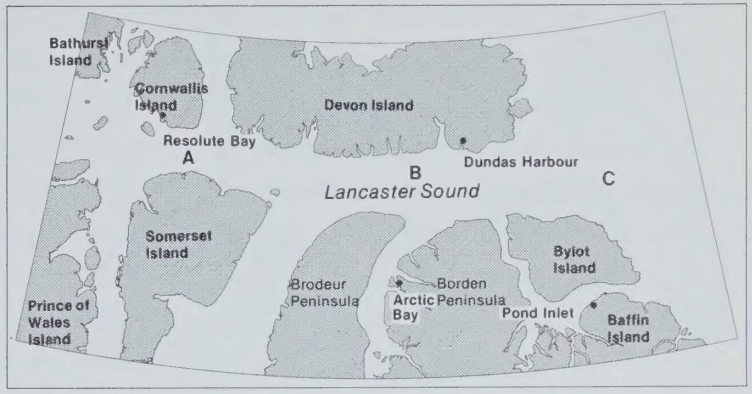
Figures 7 and 8 show the percentage frequency of occurrence of wind-speed classes at both marine areas and Resolute. As the open-water season progresses from July to October, there is an increase in the frequency of higher wind speeds, as would be expected with the increase in cyclonic activity during the fall. This is reflected at both land and marine locations.

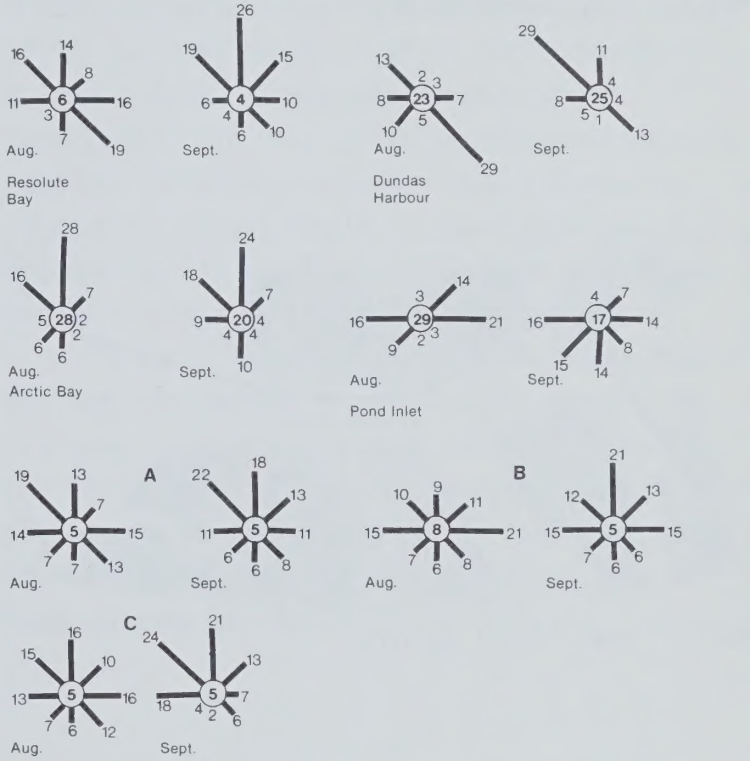
Extreme hourly wind speeds observed at the four land stations are given for each month in Figure 9. Figure 10 shows estimated extreme wind speeds for the July-to-October period in Lancaster Sound. These are given for various durations ranging from one minute to 24 hours. For example, the estimated extreme hourly wind speed for a 20-year return period is 57 kn. Information on the directional frequency of such strong winds is not directly available; however, observed winds over 34 kn at both Resolute and offshore areas suggest that while such winds may occur from any direction, 30 to 50 percent of them will be from the east or northeast. Duck et al. (1977) give a



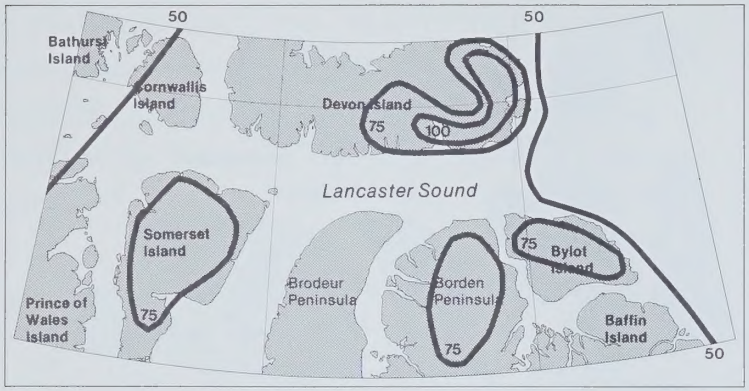


Map 9 Jan., April, July, Oct. Wind Roses

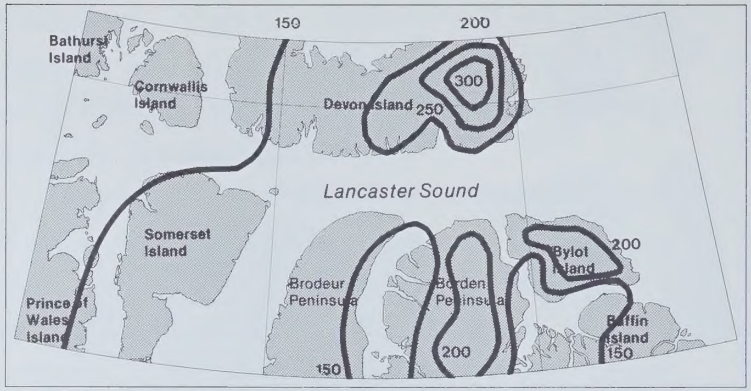




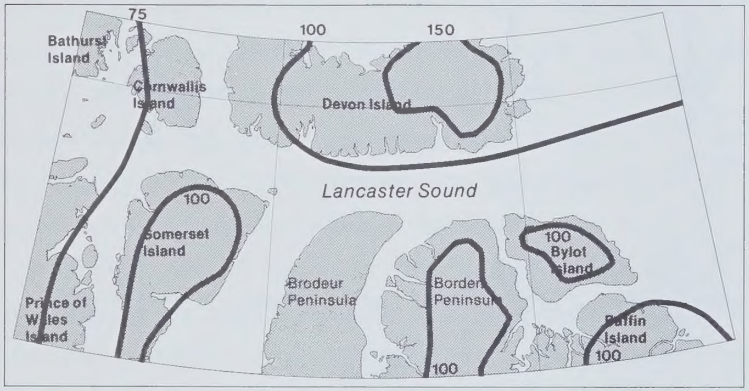
Map 10 Aug. and Sept. Wind Roses



Map 11 Mean Annual Rainfall



Map 13 Mean Annual Precipitation



Map 12 Mean Annual Snowfall

more complete discussion of the question of extreme winds.

Wind Chill (Figures 11 and 12)
Wind chill is a measure of the cooling effect of combined wind and air temperature conditions. Figure 11 shows a nomogram used to define seven comfort classes that people may feel when exposed to progressively higher wind speeds and lower temperatures. The frequency with which such classes occur at both Dundas Harbour and Resolute is shown in Figure 12. Values are given for every second month of the year. Severe conditions as exemplified by classes V to VII are common from November to March although it is apparent that, in general, conditions are less severe in eastern Lancaster Sound than in Barrow Strait to the west (as suggested by Dundas Harbour and Resolute respectively).

Precipitation (Maps 11 to 13 and Figures 13 to 14)
The patterns of mean annual rainfall, snowfall, and precipitation for the Lancaster Sound area are shown on Maps 11 to 13. The source of most of the precipitation throughout the year is the cyclonic activity following the Davis Strait trajectory into northern Baffin Bay. The resulting precipitation is enhanced by the high elevations of the eastern portions of the islands which cause significant lift of the onshore air flows. North of the sound, the "north open water" is a significant contributor of low-level moisture. Within the area of interest, Devon Island has the highest annual precipitation with totals in excess of 300 mm. The coasts of north Baffin and Bylot islands receive appreciable amounts of precipitation in the fall while Lancaster Sound is open and the prevailing winds have a northerly component. Annual totals in those areas are over 200 mm. On all these maps, a gradual decrease in annual values from east to west is noticeable.

Figure 13 indicates the mean monthly rainfall and snowfall amounts at the coastal observing stations. July and August are the months of maximum rainfall as would be expected. October is the time of maximum snowfall. In Figure 14, mean monthly total precipitation and maximum 24-hour precipitation are shown.

Structural Icing (Figure 15)

Structural icing in a marine environment can be separated into fresh-water icing and salt-water icing.

Fresh-water ice accumulation occurs when water supercools in the atmosphere or wet snow freezes at temperatures of 0°C or below. The best-known example of supercooled moisture is freezing rain or drizzle. In the Lancaster Sound area, it is estimated that there are 25 to 50 hours of such precipitation annually. At such high latitudes, supercooled advection fog or steam fog can be a significant contributor to fresh-water icing.

Although fresh-water icing frequently forms a hard glaze that is difficult to remove, salt-water icing is considered more hazardous in the Lancaster Sound area due to the nature and condition of its formation. It usually occurs when supercooled sea spray strikes the superstructure of a vessel or marine platform. This happens during storms when spray is blown from wave crests and is thrown against the vessel or platform by the waves. The amount of spray depends on the shape and design of the structure and on how it is positioned in the sea to minimize wave impact.

Figure 15 illustrates estimated extreme superstructure icing accumulations during the July-to-October period for Lancaster Sound (Duck et al., 1977) and northwestern Baffin Bay (Maxwell et al., 1979). A 20-year extreme accumulated ice amount for Lancaster Sound is estimated to be slightly greater than 12 cm for a single storm during the open-water season. An average of 22 hours of severe icing (a rate of 7 cm/24 h or greater) may be expected per season.

Aircraft Icing (Figure 16)

An indication of the likelihood of occurrences of aircraft-icing over Lancaster Sound can be gained from the northern-hemisphere aircraft icing climatology prepared by Heath and Cantrell (1972). Figure 16, derived from their study, indicates the probability of encountering icing conditions at four levels of the atmosphere. The double peaks of probability of icing in spring and fall at the lower levels of the atmosphere are to be noted. The probabilities in the figure may be interpreted as percentage frequencies of occurrence; for

example, the October probability of 0.1 for 85 kPa suggests an occurrence frequency of 10 percent.

The occurrence of icing frequencies suggested in Figure 16 appear to be somewhat lower than might be expected for the area of interest. During the summer particularly, arctic stratus can be a potential icing hazard, especially for helicopter operations. As low ceilings (less than 350 m) are possible up to a third of the time and as levels where freezing occurs can be low in the arctic atmosphere at that time of year, there is a possibility of icing during a large proportion of the time that low ceilings are reported.

Waves (Figures 17 and 18)

Figure 17 shows the percentage frequency of occurrence of observed (significant) wave heights for the marine grid points during August and September. In each of three cases, it is seen that rougher seas have occurred in September than in August. Wave heights greater than or equal to 2.4 m are increasingly more frequent as one moves from west to east towards Baffin Bay in September.

Estimated extreme significant wave heights for the July-to-October period have been obtained by Duck et al. (1977) for Lancaster Sound and Maxwell et al. (1979) for northwestern Baffin Bay. These are shown in Figure 18. A 20-year extreme significant wave height for Lancaster Sound is estimated at 5.5 m. In northwestern Baffin Bay, the uninterrupted distances winds can travel are typically less restricted by ice or land surface and the corresponding extreme wave is 8.1 m.

The significant wave height referred to here is the average height of the highest one-third of all waves observed. The highest wave is estimated to be 1.8 times this value. Accordingly, the values mentioned in the previous paragraph should be multiplied by this factor to give extreme waves as opposed to extreme significant waves.

Ceilings and Visibility (Figures 19 to 24)

The percentage frequencies of occurrence of wind direction by visibility class for each marine grid area are given in Figures 19 to 21. The months of August through October are considered. For area #10, restricted visibilities ($<$ 1 nautical mile) are associated with easterly winds most frequently in August. This switches to southeasterly in September and southerly by October for the same area. Easterly or westerly winds are those most frequently associated with restricted visibilities

at grid #11 throughout the period. For area #12, the most frequent direction is northeasterly in August and September, switching to the northwest-to-southwest quadrant in October.

For the same visibility classes as in Figures 19 to 21, the percentage frequencies of occurrence of wind speed are shown in Figure 22. In virtually every month at the three marine grid points, restricted visibilities are mainly associated with winds in 4 to 10 kn range.

Figures 23 and 24 show the percentage frequency of occurrence of combined ceiling and visibility classes for both the marine areas and Resolute. At Resolute, for which data are available throughout the year, the most restricted ceiling and visibility conditions occur in July when fog and low stratus are most prevalent. A second high point occurs in winter when blowing snow is an important visibility-reducing agent. The marine grid points also indicate more frequent reduced ceiling and visibility conditions in August than in either of September or October.

Air Pollution Potential (Figures 25 to 28)

The characteristics of the area of interest in terms of air temperature inversion frequency, calm-to-light wind occurrence, and ventilation coefficients are of particular importance in considering its air pollution potential.

Figure 25 indicates the monthly percentage frequencies of occurrence of surface-based inversions and inversions based within 300 m of the surface for Resolute. The dominant presence of the arctic inversion is reflected in the winter frequencies. Values of 20 to 30 percent are typical of the summer, but with the September increase in cyclonic activity, there is a marked decrease in surface-based inversion frequency before the arctic inversion redevelops in October and November.

The occurrence of calm and calm-to-light (0 to 3 kn) winds is an important factor in the persistence of air pollution. Data of this nature are given in Figures 26 and 27 for both marine and coastal locations. From the coastal stations, maximum durations of calms have been determined to be near 25 hours in summer, increasing to over 100 hours in winter.

"Ventilation coefficient" is the term used to denote the product of the mixing height

(atmospheric layer through which dispersion takes place) and the mean transport wind speed in that layer. The higher the value of the coefficient the more able the atmosphere is to disperse pollutants. For temperate latitudes, a value of 6 000 m^2/s has been used as a relative indicator of low air pollution potential. On this basis, Lancaster Sound (as indicated by Resolute data) is very pollution prone throughout the year, but especially in winter. This is shown in Figure 28, based on data from Portelli (1978).

DATA DEFICIENCIES

While there is a reasonable understanding of some components of Lancaster Sound climate, a marked improvement in all types of meteorological data gathering is necessary because of the scientific, ecological, and commercial interest in the area.

The existing offshore data base is at present restricted to the open-water season, with most observations concentrated in the months of August and September. The inadequacy of 8 000 surface observations that are available for the three marine grid points over the last 32 years may be judged by comparison with an hourly observing station program that would result in almost 9 000 observations being taken at one site in only one year. No offshore data are available for the winter months when the sound is ice covered.

In regard to land stations, only Resolute has a continuously recording, surface, hourly program with a long period of record anywhere in the general area. Even it is at the extreme western end of the area of interest and is subject to some local influences. The other existing land stations are generally not very representative of conditions in Lancaster Sound. Further, their observing programs suffer from gaps in the record or observations at only six or eight hourly intervals.

Upper-air data are available only from Resolute to the west, at present. Previously, an upper-air program was also in operation at Arctic Bay, but it was discontinued in 1957.

Two major areas of concern result from the existing data base. Firstly, although estimates have been made of extreme occurrences of various climatic or related elements (such as wind, waves,

and structural icing) for Lancaster Sound as a whole, there is no great understanding of what areal variations may exist within the sound itself. Secondly, reliable duration analyses are not generally available. The only station for which such analyses may usefully be prepared is, again, Resolute with its hourly observing program. Even there, there is some doubt about the value of certain duration analyses. For example, peculiarities in the wind regime due to occasional shooting flows (Fraser, 1959) can make wind-duration analyses unreliable.

FURTHER STUDY

There are two major areas requiring further study that should be considered: extreme storms and climatic variations.

Extreme Storms

A start has been made on addressing this problem at the Arctic Weather Centre of AES (Maxwell et al., 1979) where a brief climatology of extreme storms has been developed for the northwestern Baffin Bay area. A storm is defined as any occurrence of gale-force winds (35 kn) or stronger for a period of at least six hours. This climatology covers storms from the open-water seasons of 1974-1978. Case studies of several of these storms have been prepared. Further development of this approach is needed, in particular, an extension of the climatology to 25 or 30 years so that the more recent season data can be put into perspective in terms of long-term conditions.

Climatic Variations

The possibility of climatic variation during at least the remainder of this century needs to be taken into account in any determination of Lancaster Sound use, based on the material outlined in this paper. If variations or trends in climate are sufficiently large, the historic period used for the analyses presented here could be significantly unrepresentative of the future.

While episodes of both cooling and warming will occur in the short term, the best evidence now available indicates the likelihood of a long-term warming trend resulting from increased atmospheric carbon dioxide levels, such that significantly warmer conditions will prevail in the Arctic beginning in the first half of the next century. The most likely results of this would be

decreases in the thickness of first-year ice and in the concentrations of old ice that could affect the Lancaster Sound area. A longer open-water season would also be expected. The latter would suggest that an offshore activity such as drilling for hydrocarbons could be extended well into November on a regular basis. On the other hand, such an operation would then be prone to the severe storm activity of November and to an increased frequency of severe high waves as ice edges would no longer limit the uninterrupted distances wind can travel over water to the same extent.

Summary

A detailed understanding of the climate of the Lancaster Sound area is hindered by a lack of long, continuous observational records from either the offshore area itself or even the adjacent coastal areas. Despite such limitations, a reasonable knowledge of many of the climatic elements is felt to exist, as has been presented in this paper.

Planning and assessment of possible uses of Lancaster Sound must, however, be carried out bearing in mind that there is a definite chance that future weather events will fall outside the limits given here, and that the possibility of this happening will increase with time. It follows that in the case where an approved operation is to continue over a period of more than a few years, monitoring to detect trends is essential, and that analyses should be revised when this monitoring indicates significant changes have occurred.

REFERENCES

Berry, M.O., and Scholefield, P.R. 1979. Mean and Extreme Semi-Monthly Northwestern Hemispheric Snow Boundaries from Satellite Records (1966-1979) and Some Surface Data Comparisons. Unpublished manuscript, Atmospheric Environment Service.

Duck, P.J.; Berry, M.O.; and Phillips, D.W. 1977. A Preliminary Analysis of Weather and Weather-Related Factors in Lancaster Sound. Unpublished Project Report No. 32, Atmospheric Environment Service, Toronto.

Headley, A.N. 1979. Climatic Analysis of Dundas Harbour CCC Report, Atmospheric Environment Service (in press).

Heath, E.D., and Cantrell, L.M. 1972. Aircraft Icing Climatology for the Northern Hemisphere. Technical Report 222, USAF Air Weather Service.

Hill, S.M.; Fissel, D.B.; and Serson, H. 1978. A Study of Wind and Atmospheric Pressure in Eastern Parry Channel, N.W.T. - Summer 1977. Pacific Marine Science Report 78-21, Institute of Ocean Sciences, Sidney, BC.

Jakobsson, T. 1979. Wind Experiment in Barrow Strait, N.W.T. CCC Report No. 79-6, Atmospheric Environment Service.

Maxwell, J.B. 1979. The Climate of the Canadian Arctic Islands and Adjacent Waters. Climatological Studies Report, Atmospheric Environment Service (in press).

Maxwell, J.B.; Duck, P.J.; Thompson, B.; and Vickers, G. 1979. The Climate of Northwestern Baffin Bay. Atmospheric Environment Service Report (in press).

Portelli, R.V. 1978. Data on Mixing Heights, Wind Speeds, and Ventilation Coefficients for Canada. Climatological Studies Report No. 31, Atmospheric Environment Service.

Taylor, R.B. 1977. The Summer Climate of Cunningham Inlet, Somerset Island, District of Franklin. Paper 77-1C, Geological Survey of Canada, Ottawa.

Woodrow, R.J. 1972. Climatic Report on Pond Inlet. Unpublished report, Arctic Project Series No. 8, Atmospheric Environment Service, Toronto.

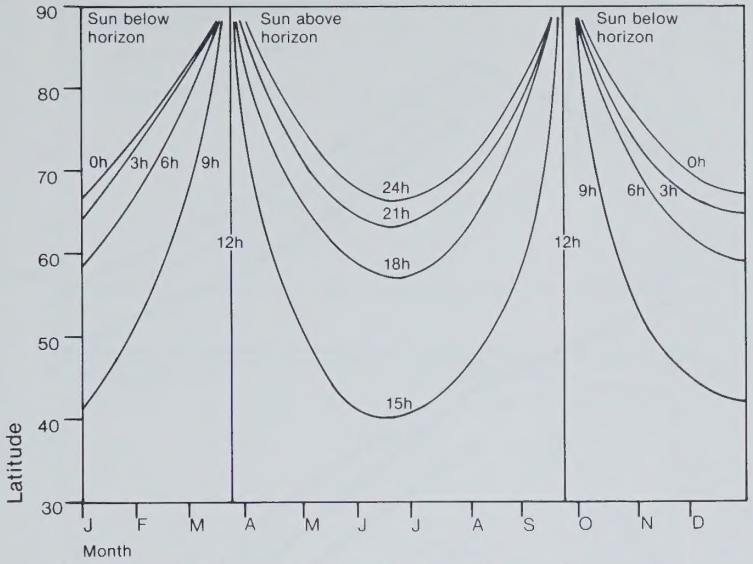


Figure 1 Duration Of Daylight (Hours)

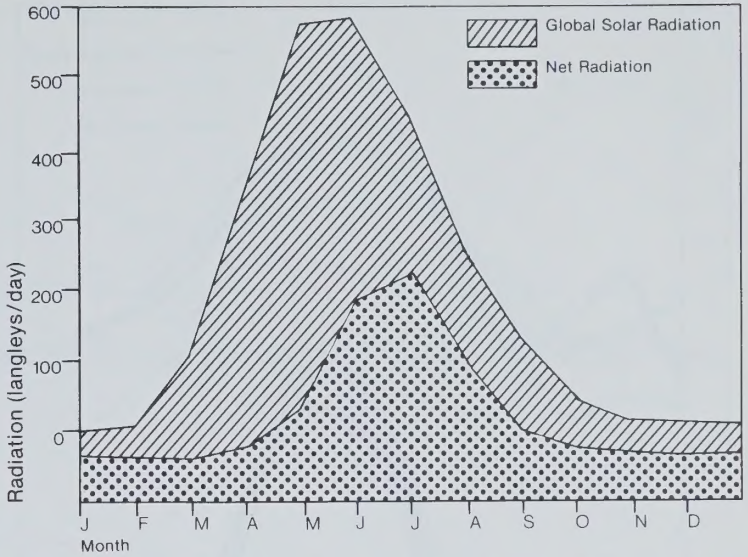


Figure 2 Mean Daily Radiation Values Observed At Resolute A (1970-1976)

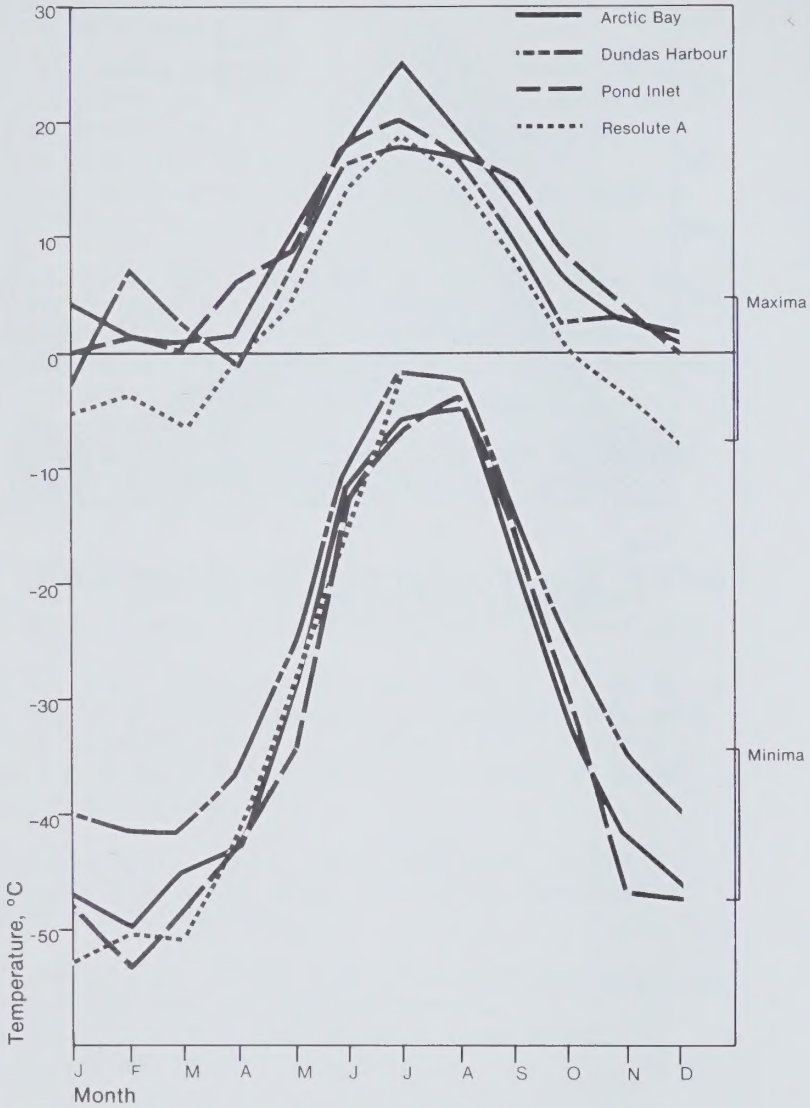


Figure 3 Monthly Extreme Temperature Values

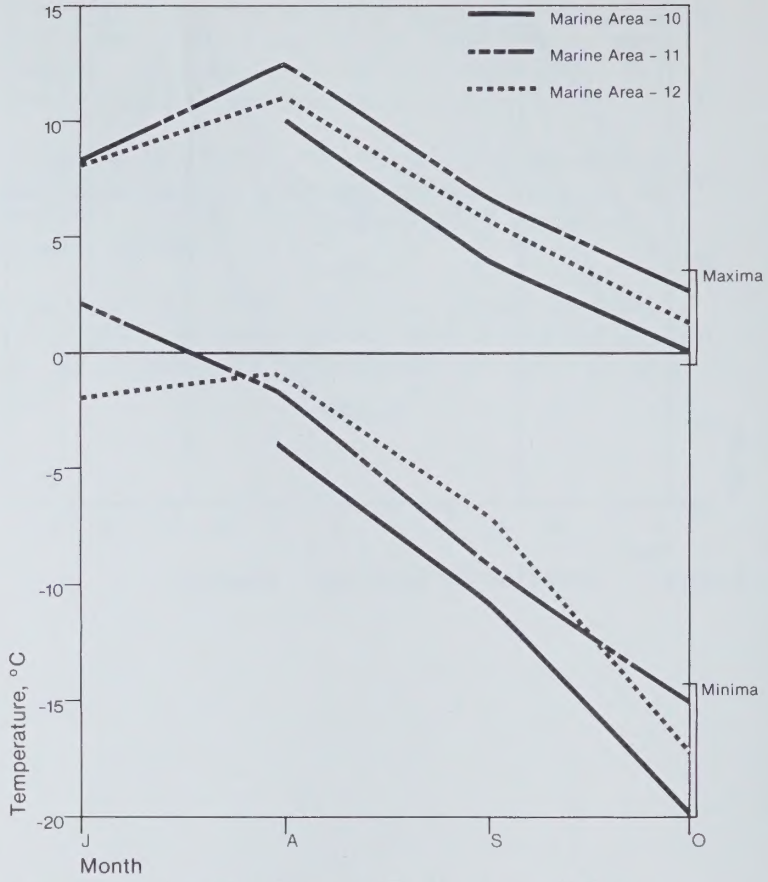


Figure 4 Monthly Extreme Temperature Values

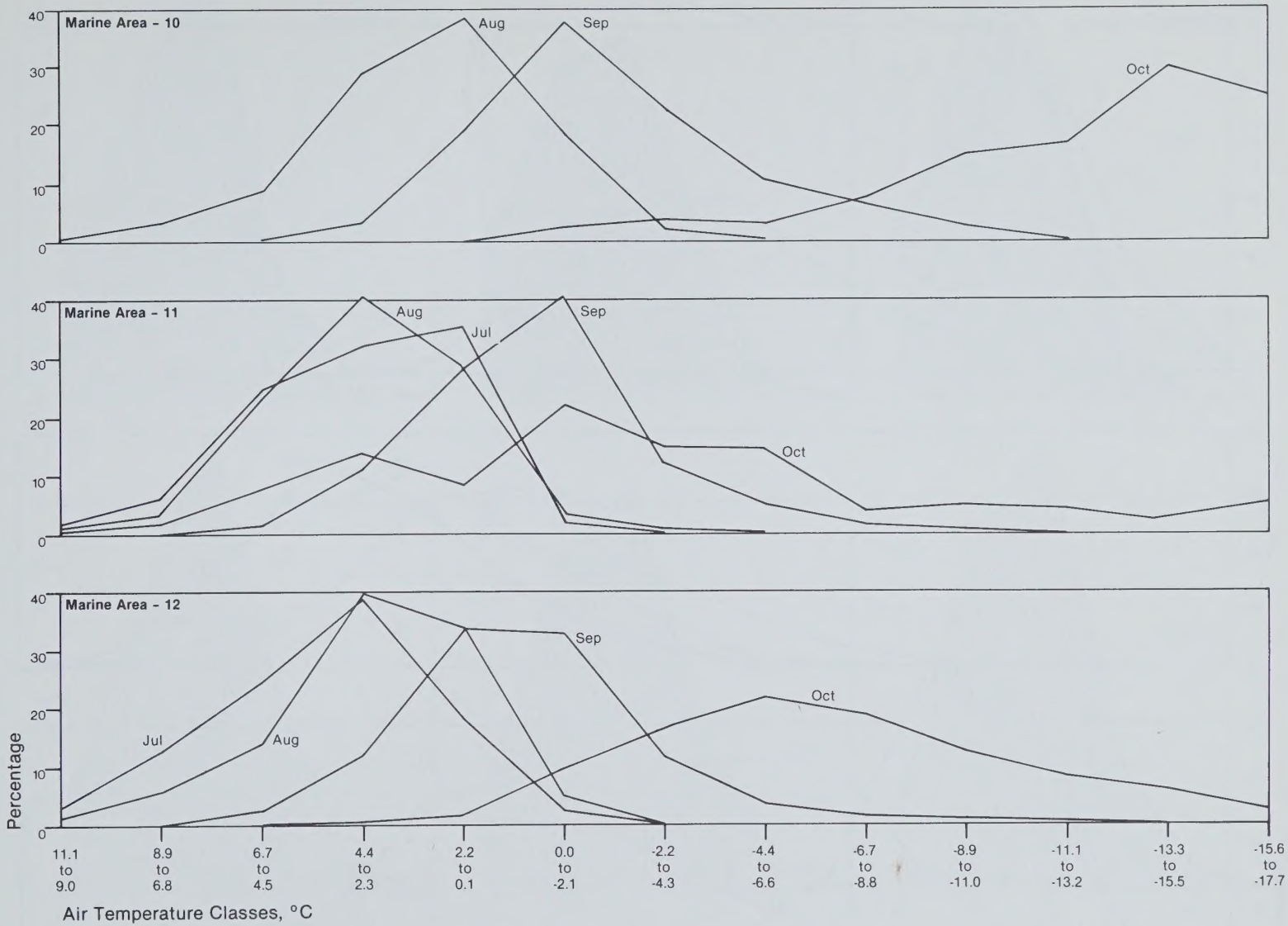


Figure 5 Percentage Frequencies Of Occurrence Of Temperature Classes For The Marine Grid Areas

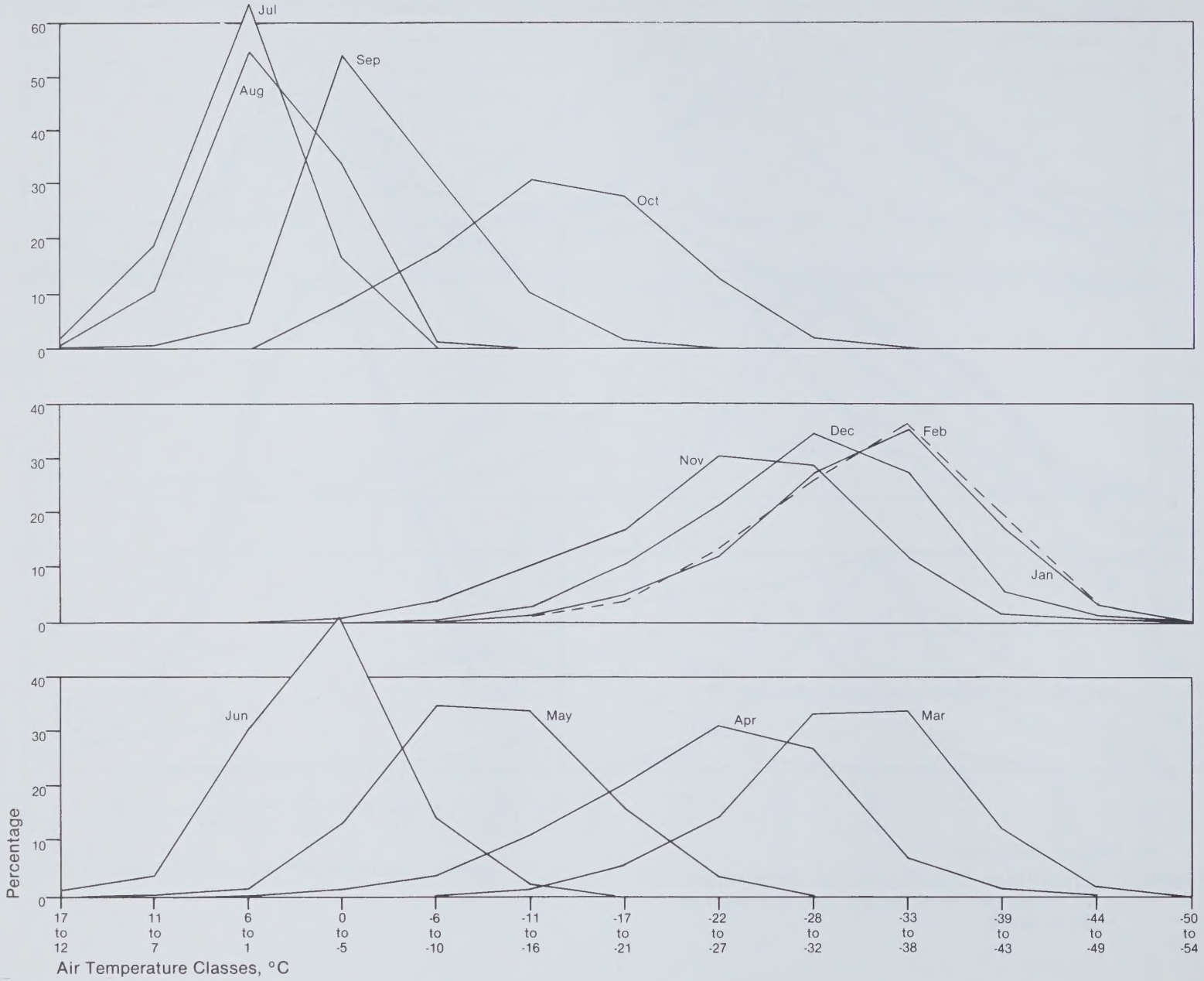


Figure 6 Percentage Frequencies Of Occurrence Of Temperature Classes For Resolute A

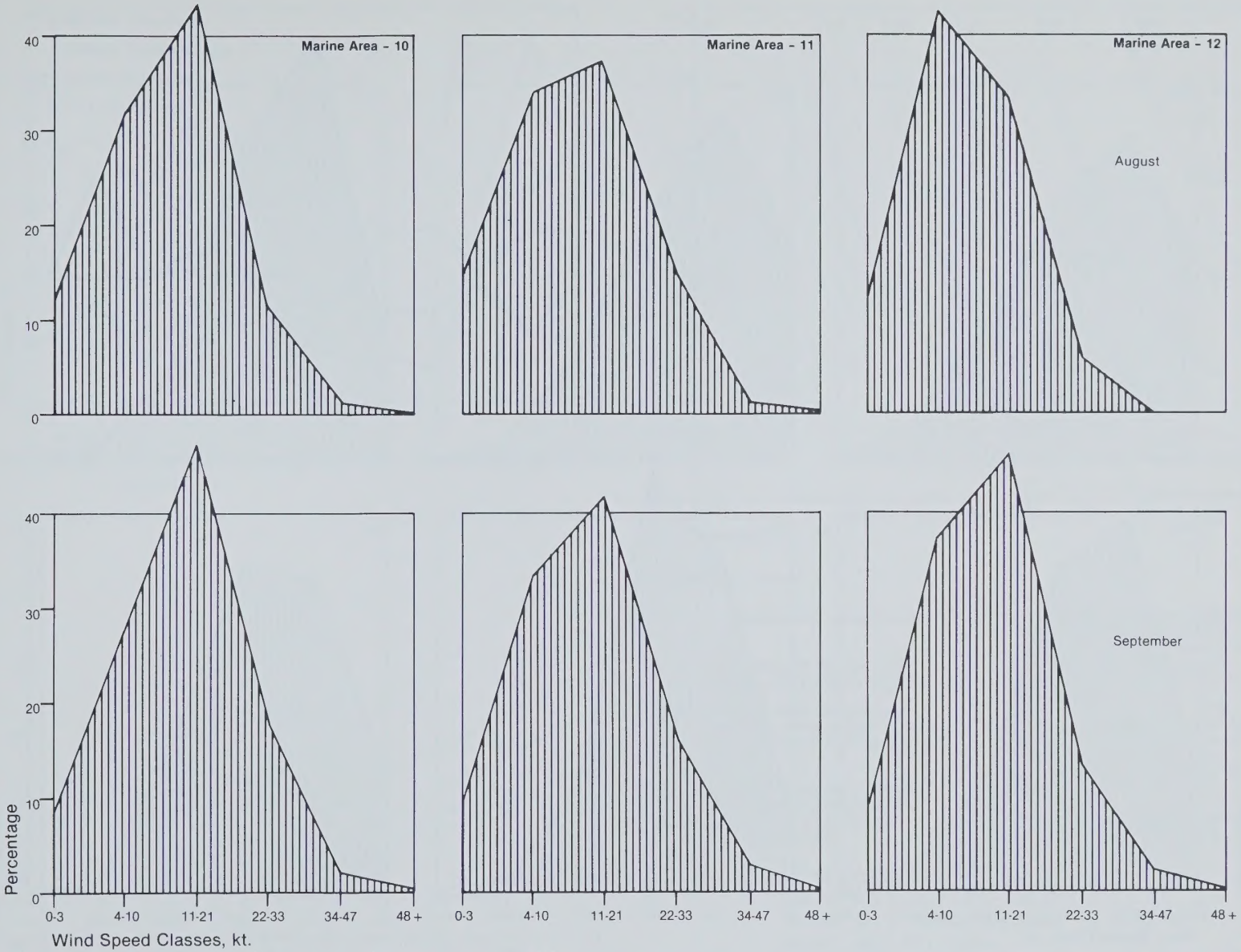


Figure 7 Percentage Frequency Of Occurrence Of Wind Speed Classes

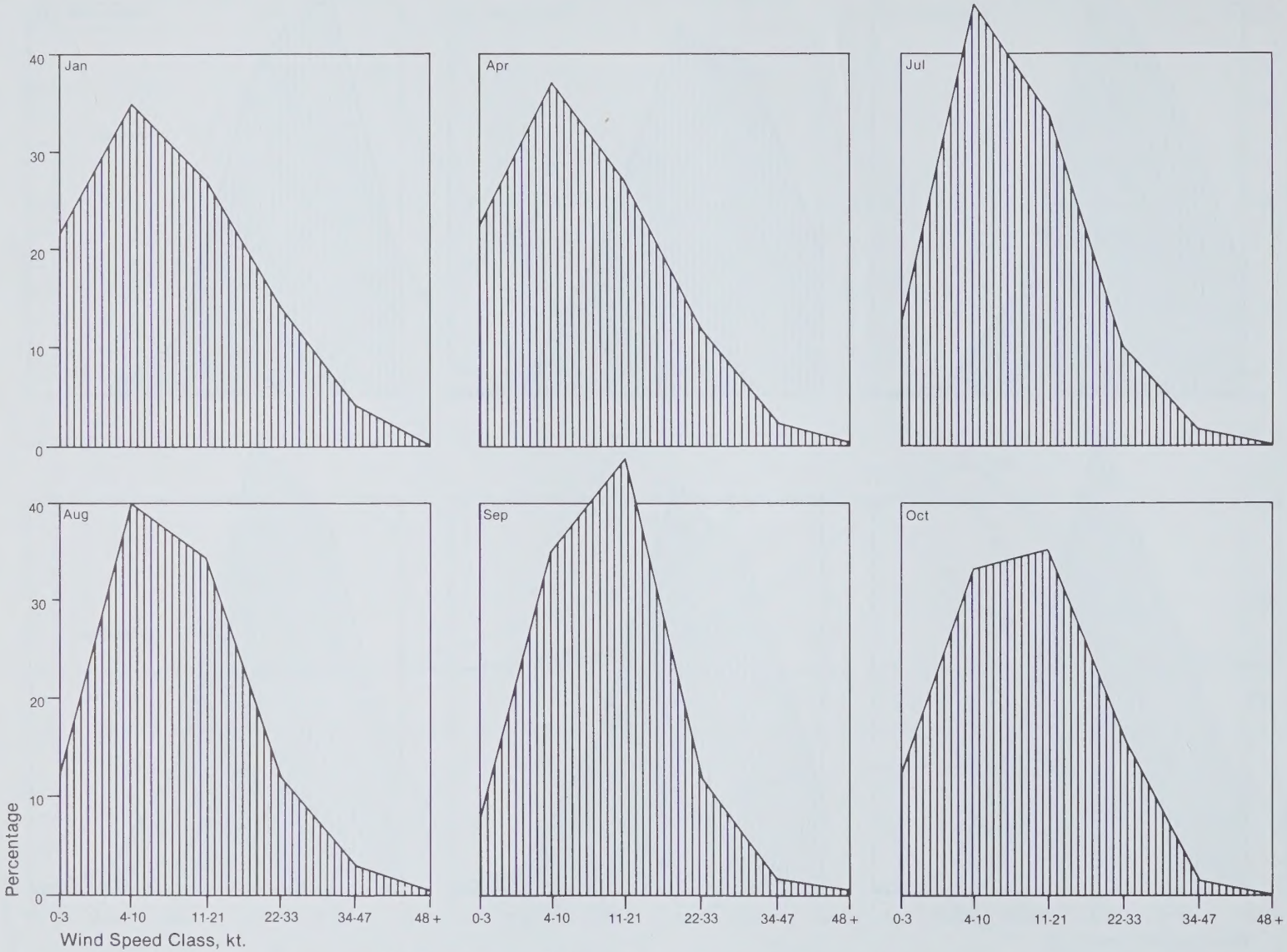


Figure 8 Percentage Frequency Of Occurrence Of Wind Speed Classes At Resolute A

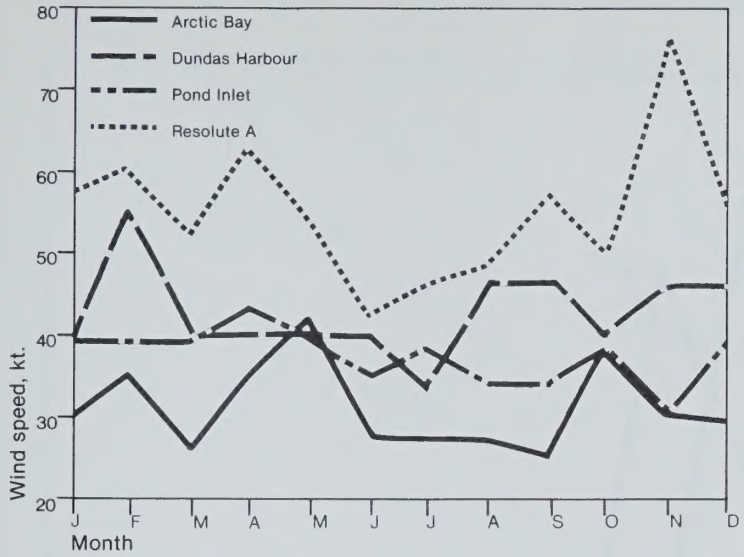


Figure 9 Observed Monthly Extreme Hourly Wind Speeds

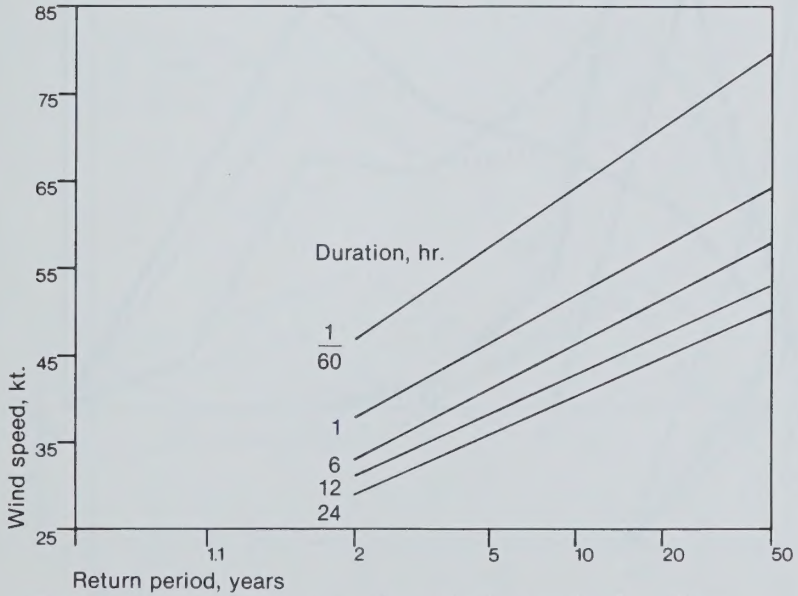
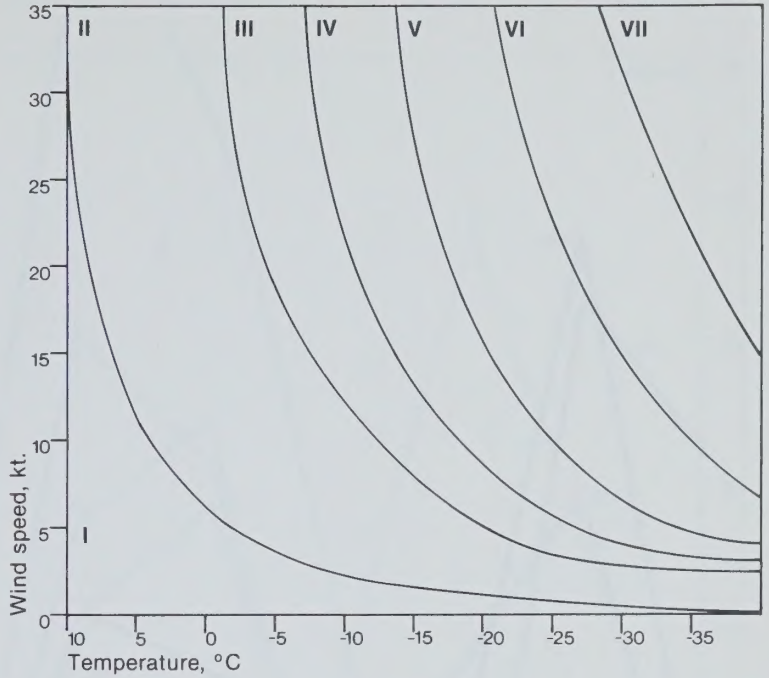


Figure 10 Estimated Design Wind Speeds For The July-to-October Period In Lancaster Sound



Comfort classes

I Comfortable with normal precaution.

II Work and travel become uncomfortable unless properly clothed.

III Work and travel become more hazardous unless properly clothed. Heavy outer clothing becomes mandatory.

IV Unprotected skin will freeze with direct exposure over prolonged period. Heavy outer clothing becomes mandatory.

V Unprotected skin can freeze in one minute with exposure. Multiple layers of clothing mandatory. Adequate face protection becomes important. Work and travel alone not advisable.

VI Adequate face protection becomes mandatory. Work and travel alone prohibited. Supervisors must control exposure times by careful work scheduling.

VII Personnel becomes easily fatigued. Buddy system and observation mandatory.

Figure 11 Wind-Chill Comfort Classes Based On Combined Wind-Temperature Effects. Based On A Nomogram Used By USAF At Goose Bay Air Base

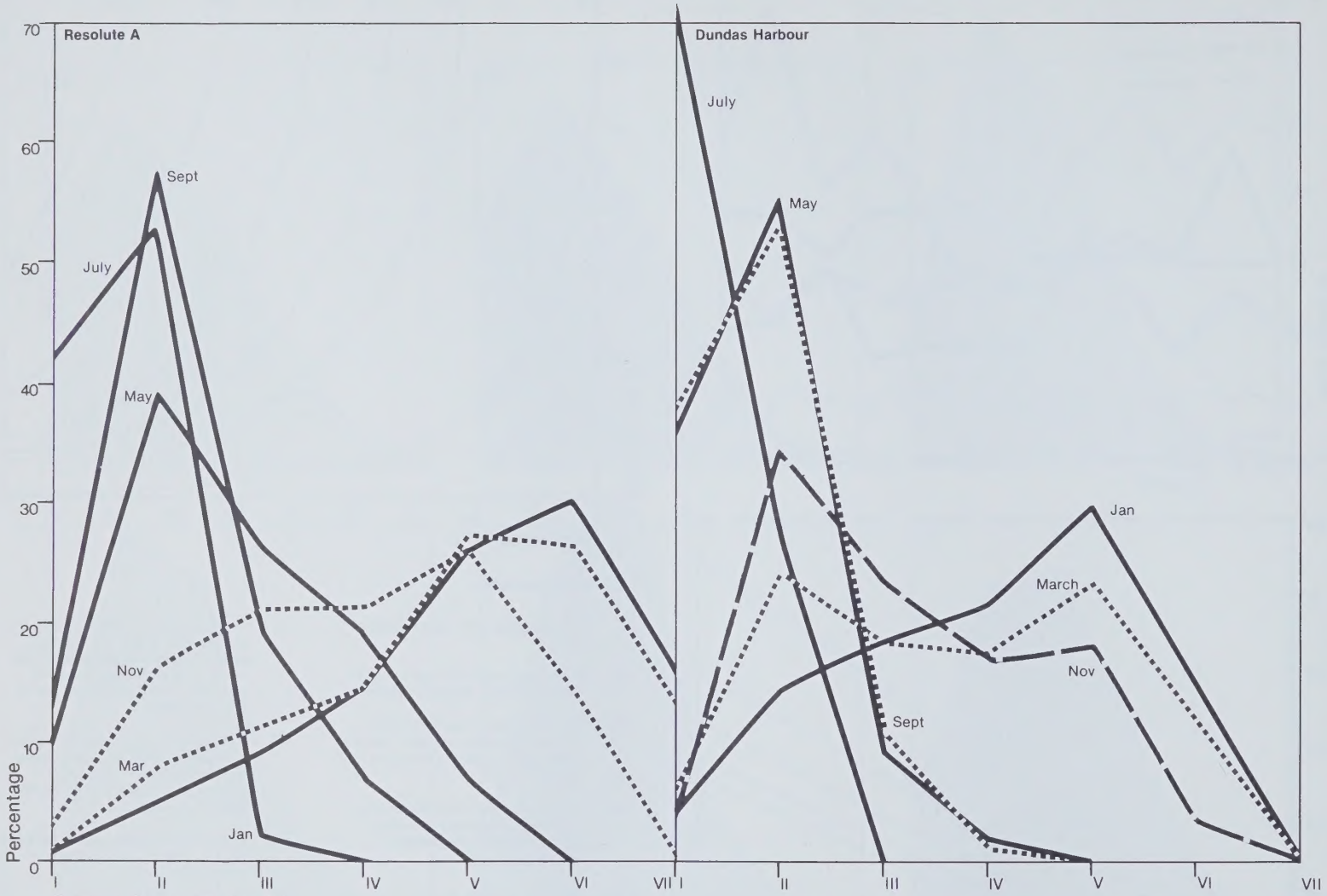


Figure 12 Percentage Frequency Of Occurrence Of Comfort Classes

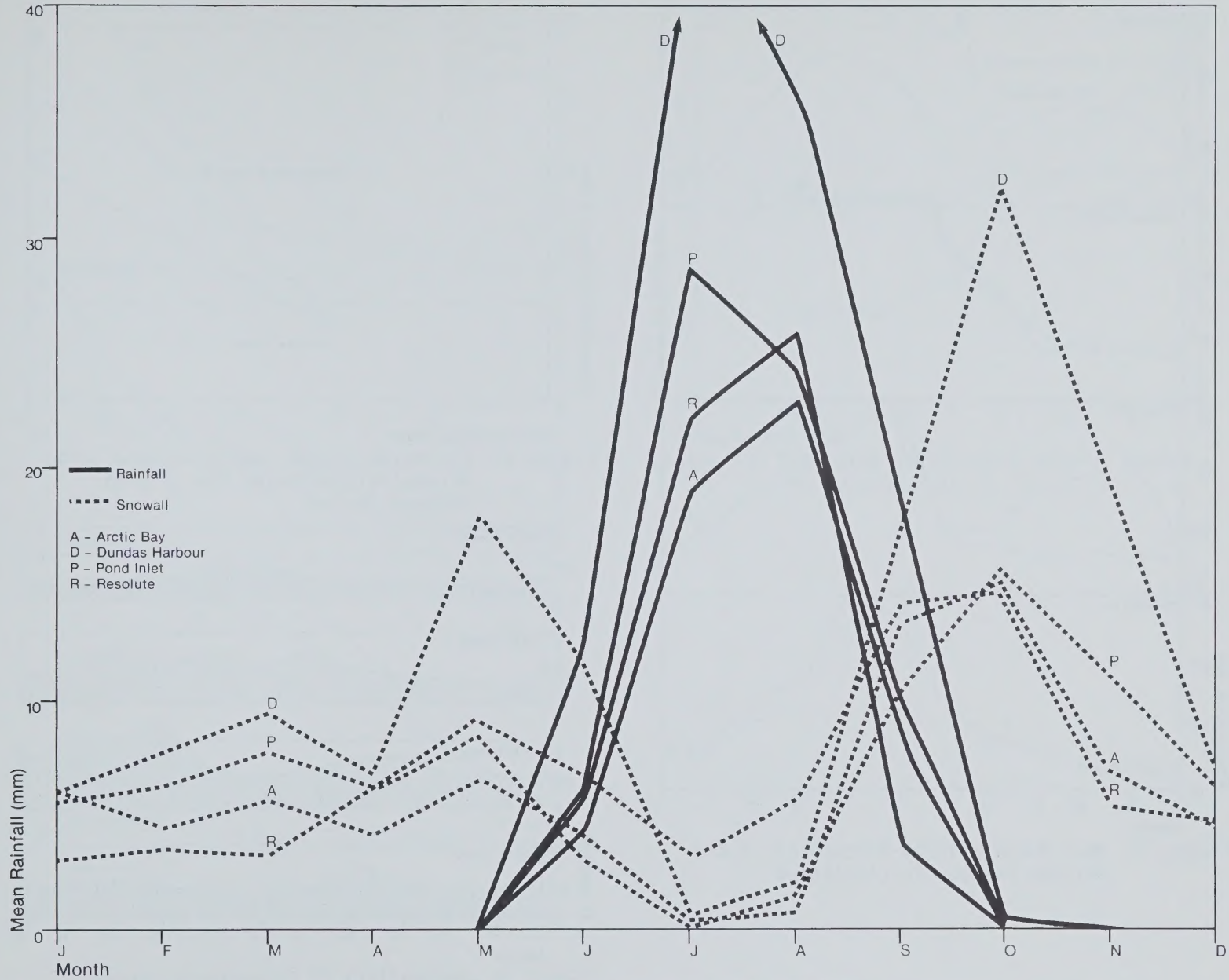


Figure 13 Mean Monthly Rainfall And Snowfall At Coastal Observing Stations

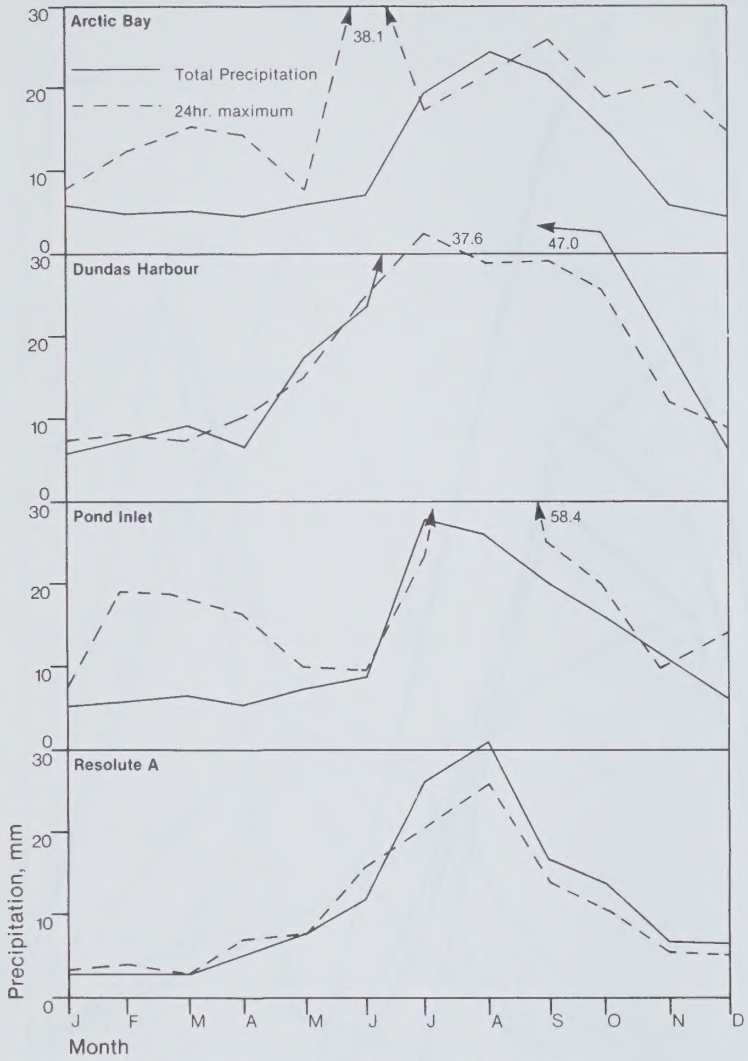


Figure 14 Mean Monthly Total Precipitation And Maximum 24-Hour Precipitation

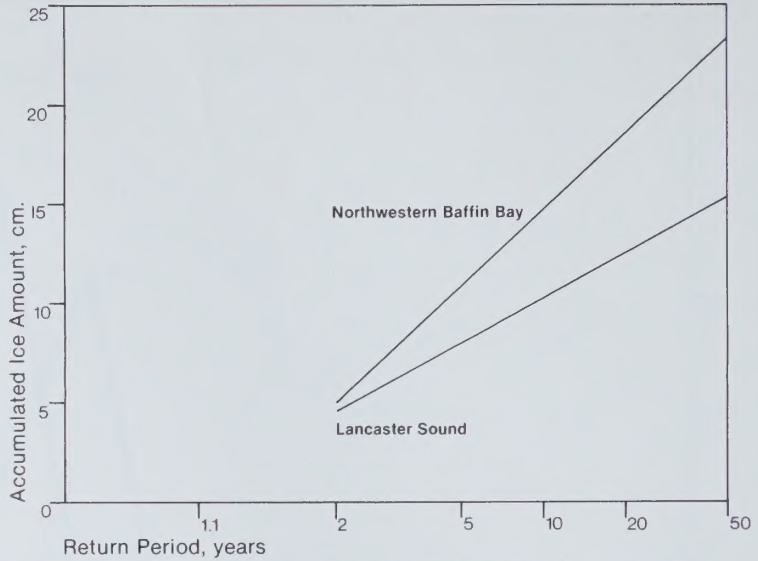


Figure 15 Estimated Design Superstructure Icing Accumulations During The July-to-October Period

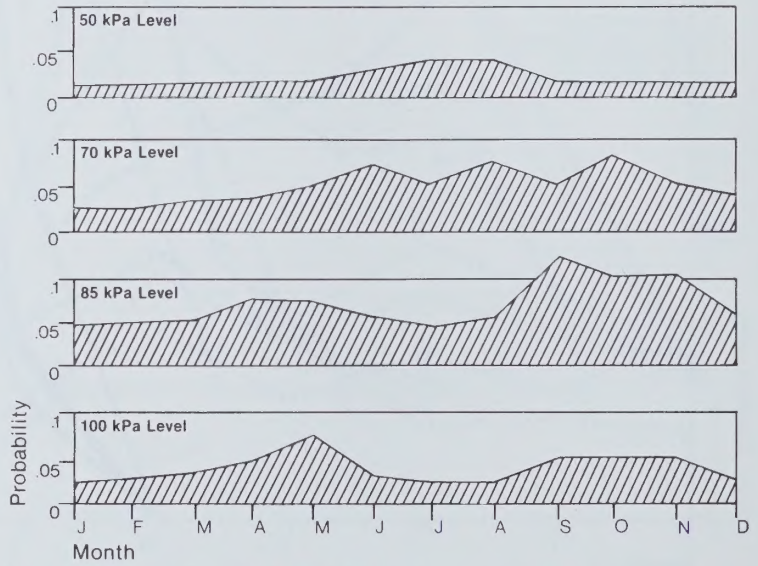


Figure 16 Probability Of Encountering Icing Conditions At Four Standard Levels Of The Atmosphere Over Lancaster Sound

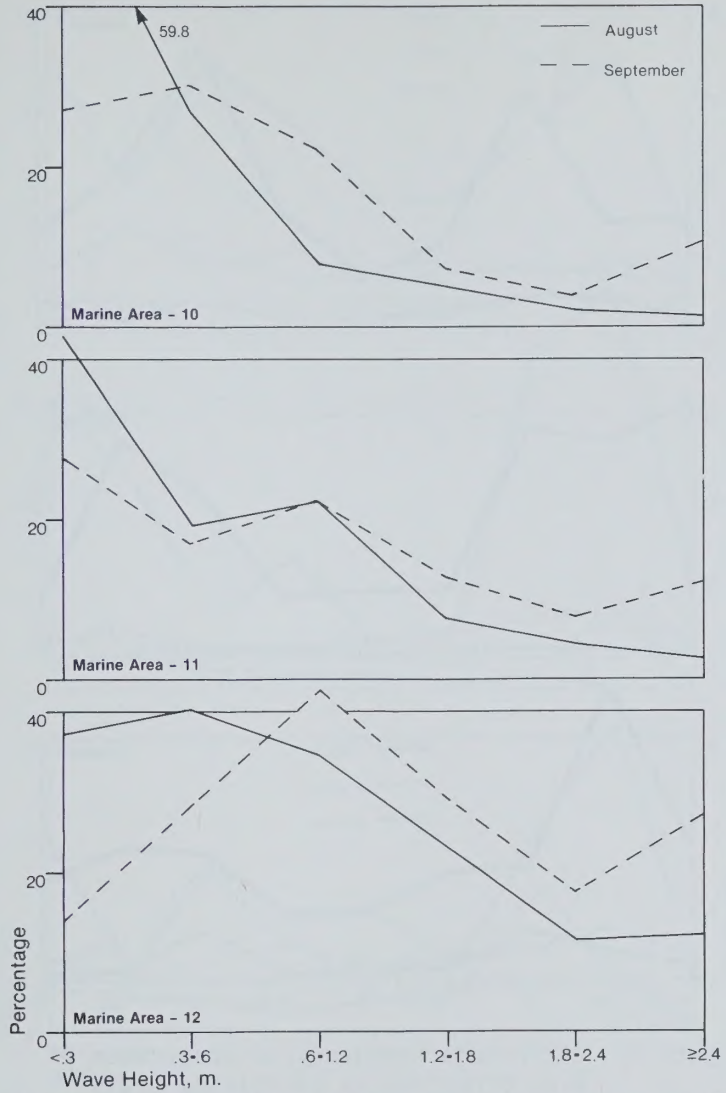


Figure 17 Percentage Frequency Of Occurrences Of Observed Wave Heights For Marine Areas

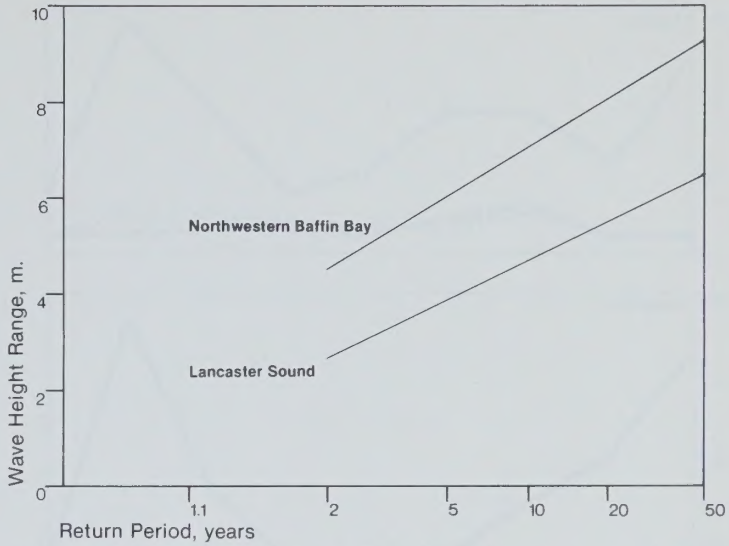


Figure 18 Estimated Design Wave Heights During the July-to-October Period

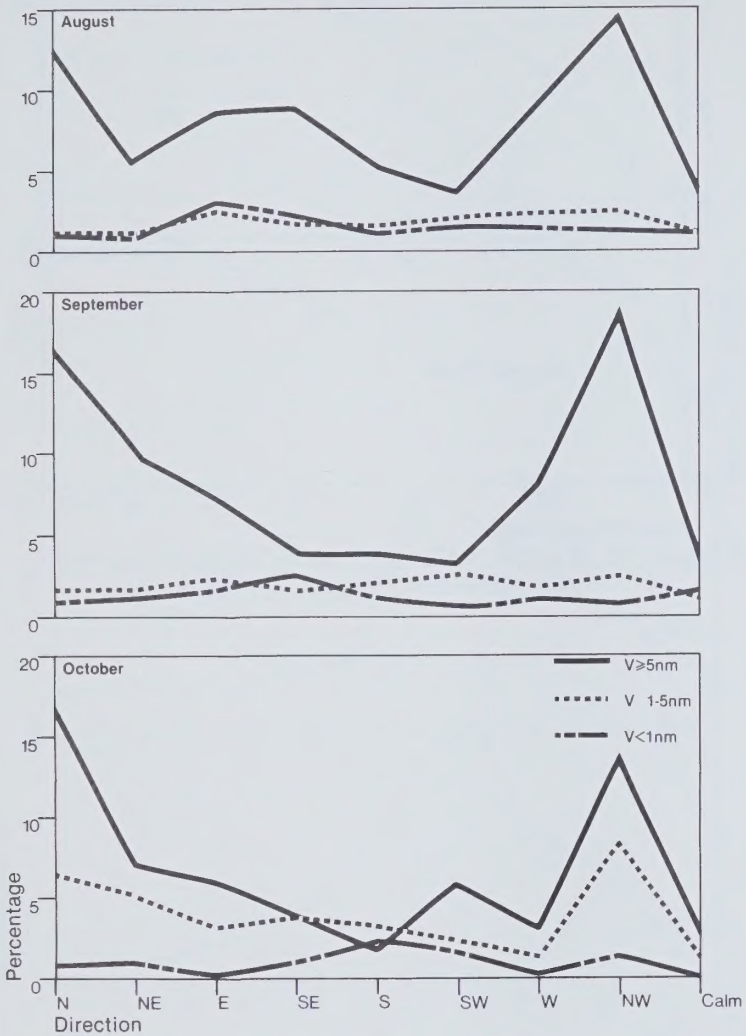


Figure 19 Percentage Frequency Of Occurrence Of Wind Direction By Visibility Class For Marine Area Number 10

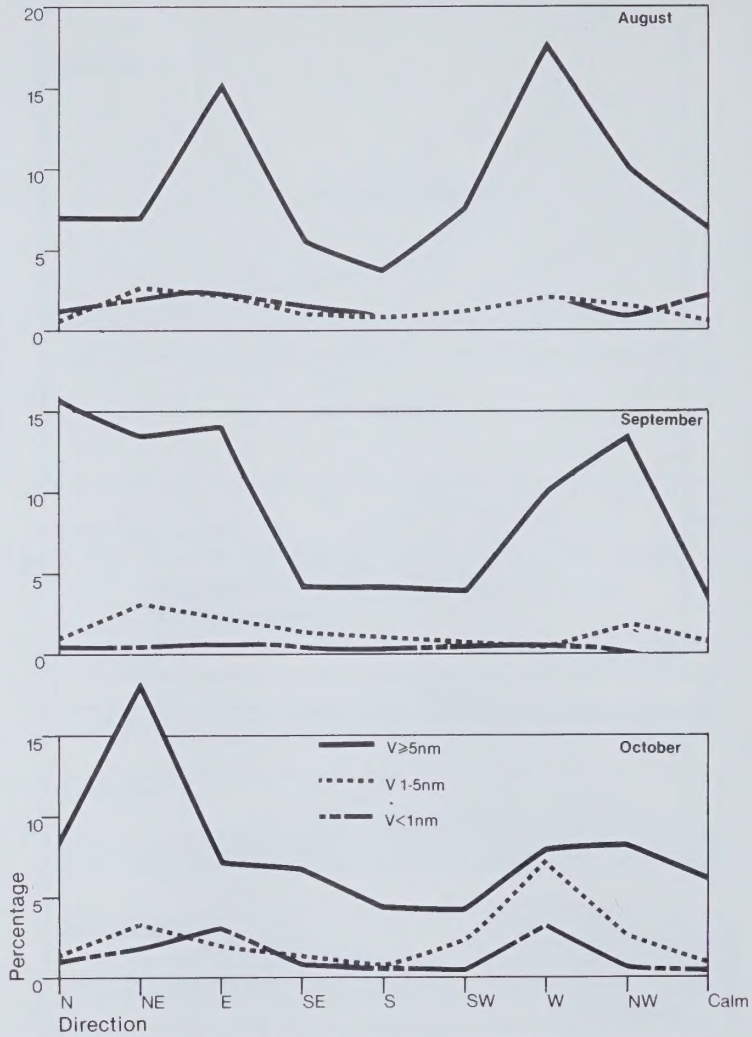


Figure 20 Percentage Frequency Of Occurrence Of Wind Direction By Visibility Class For Marine Area Number 11

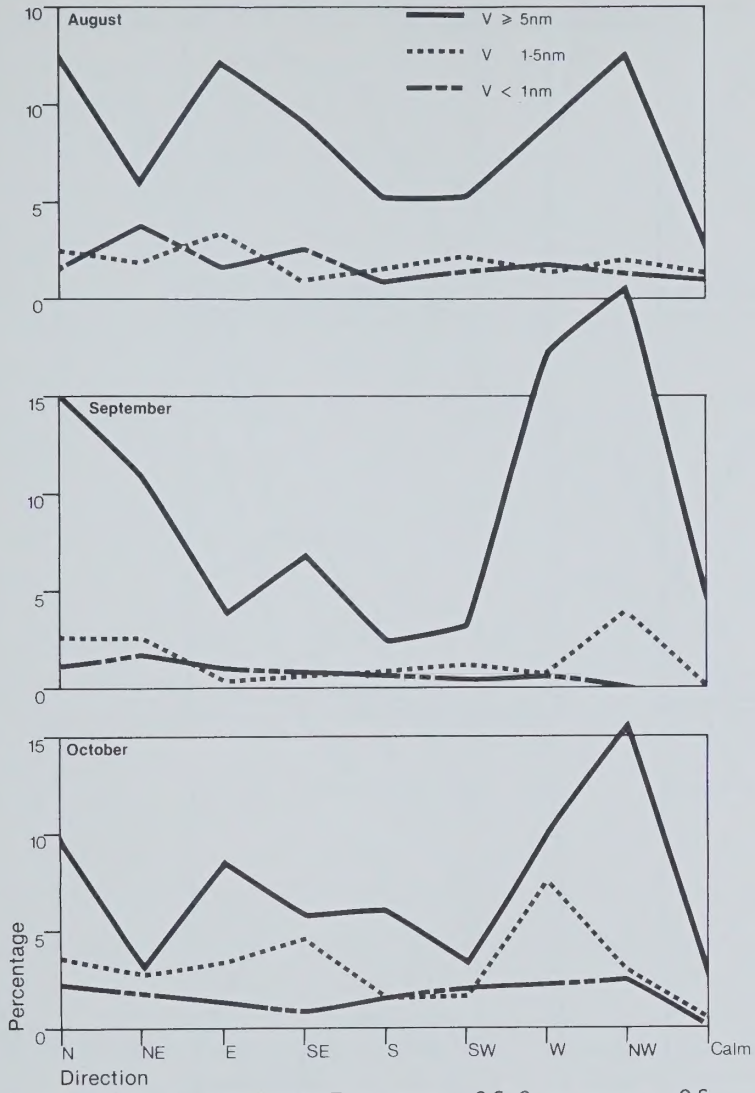


Figure 21 Percentage Frequency Of Occurrence Of Wind Direction By Visibility Class For Marine Area Number 12

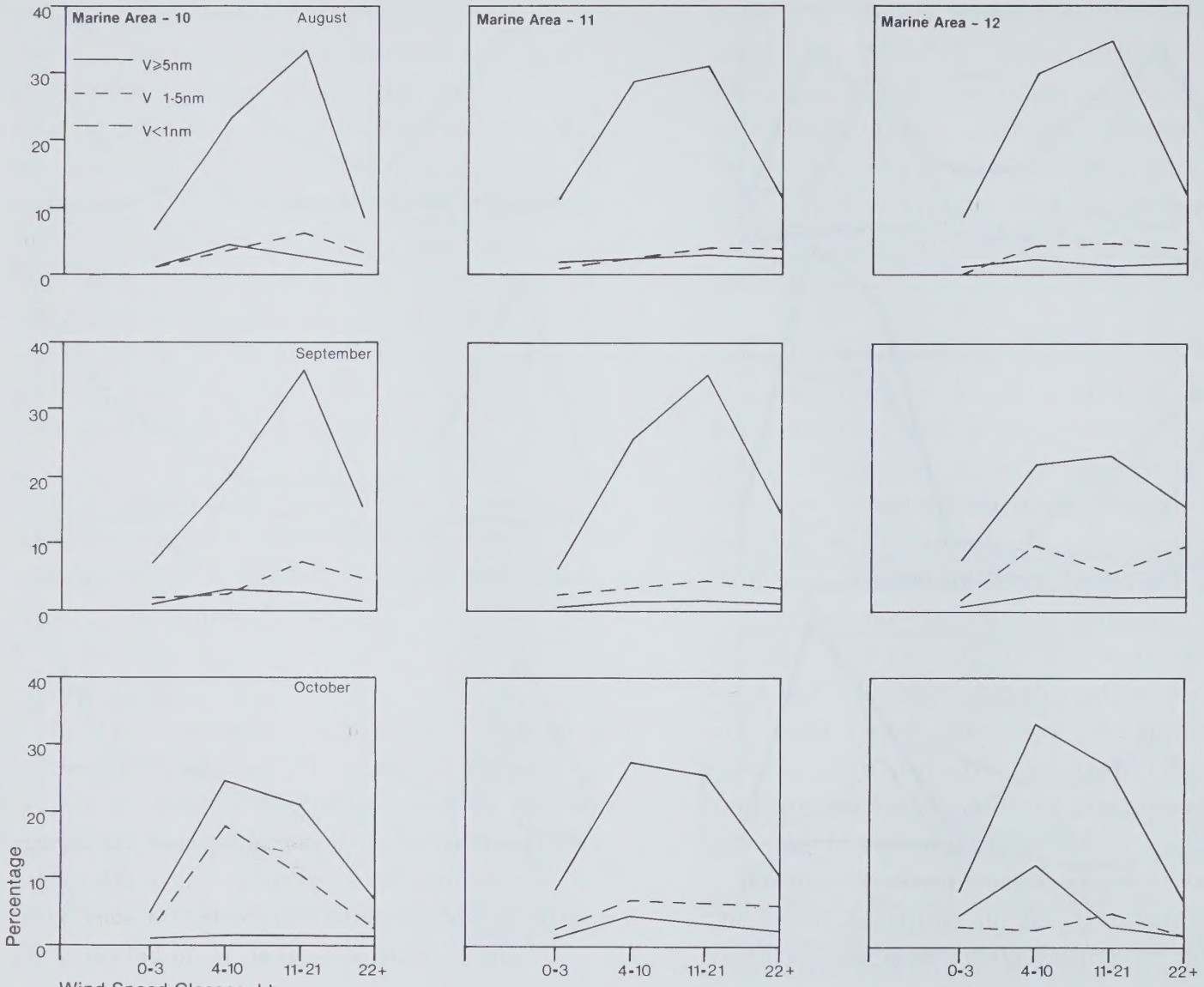


Figure 22 Percentage Frequency Of Occurrence Of Wind By Visibility Class

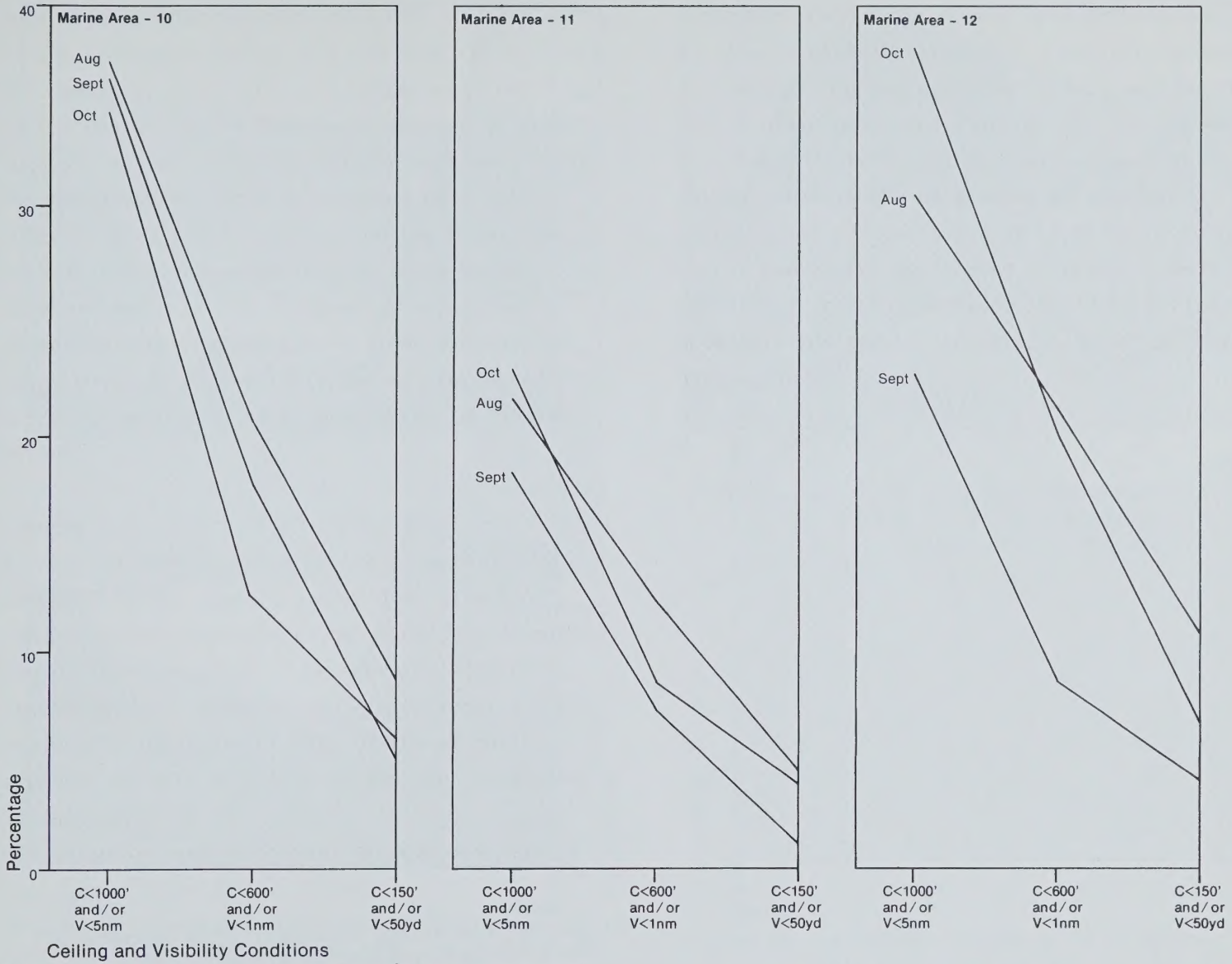


Figure 23 Percentage Frequency Of Occurrence Of Combined Ceiling and Visibility Classes For The Marine Areas

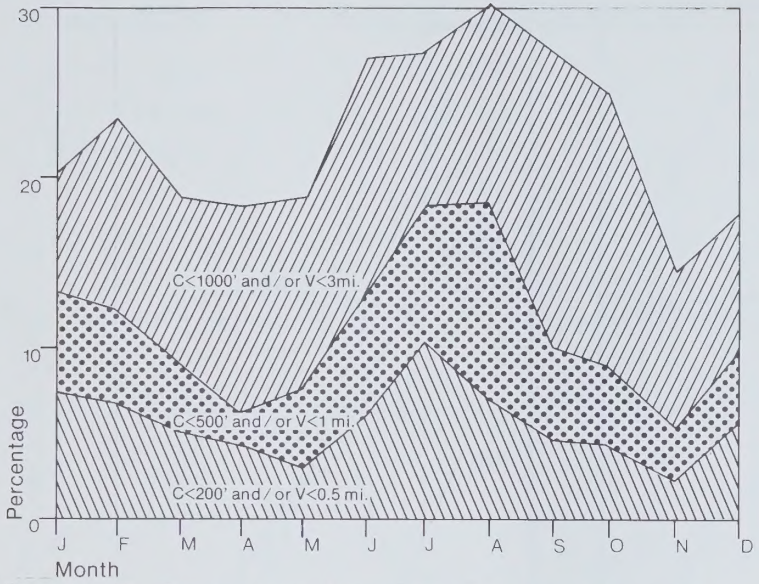


Figure 24 Percentage Frequency Of Occurrence Of Combined Ceiling And Visibility Classes For Resolute A

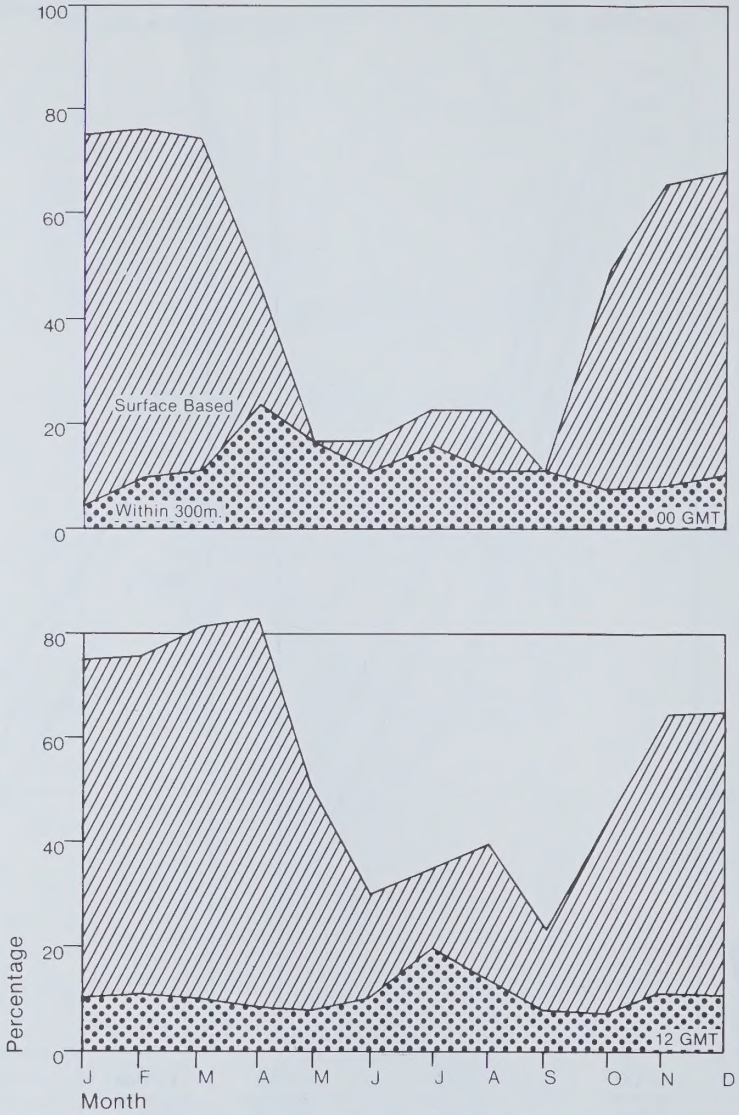


Figure 25 Percentage Frequency Of Occurrence Of Surface-Based Inversions (——) And Inversions Based Within 300 m Of Surface (----) For Resolute A

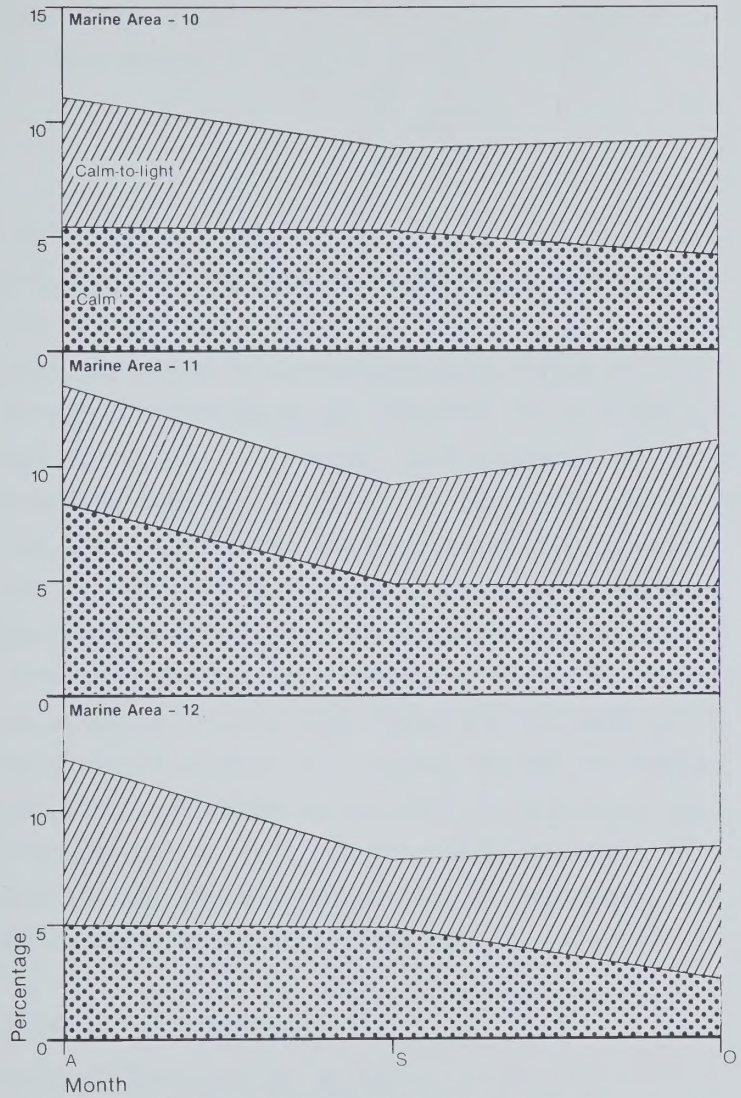


Figure 26 Percentage Frequency Of Occurrence Of Calm And Calm-to-Light (0-3 kt) Winds

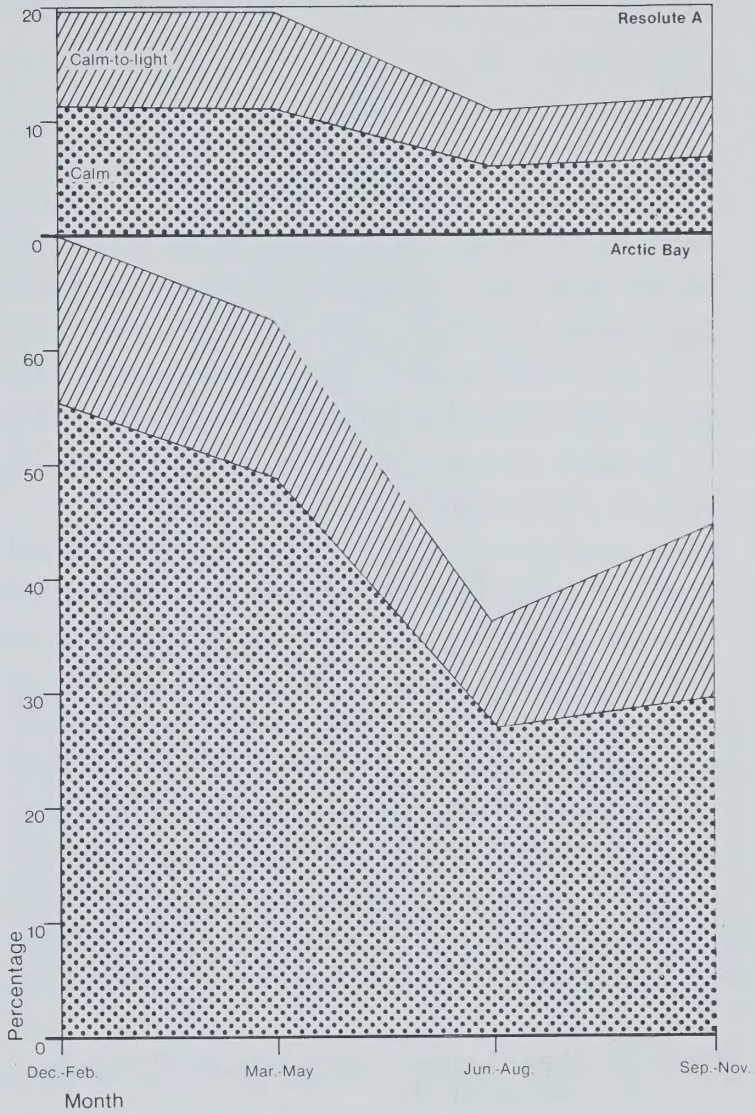


Figure 27 Percentage Frequency Of Occurrence Of Calm And Calm-to-Light (0-3 kt) Winds

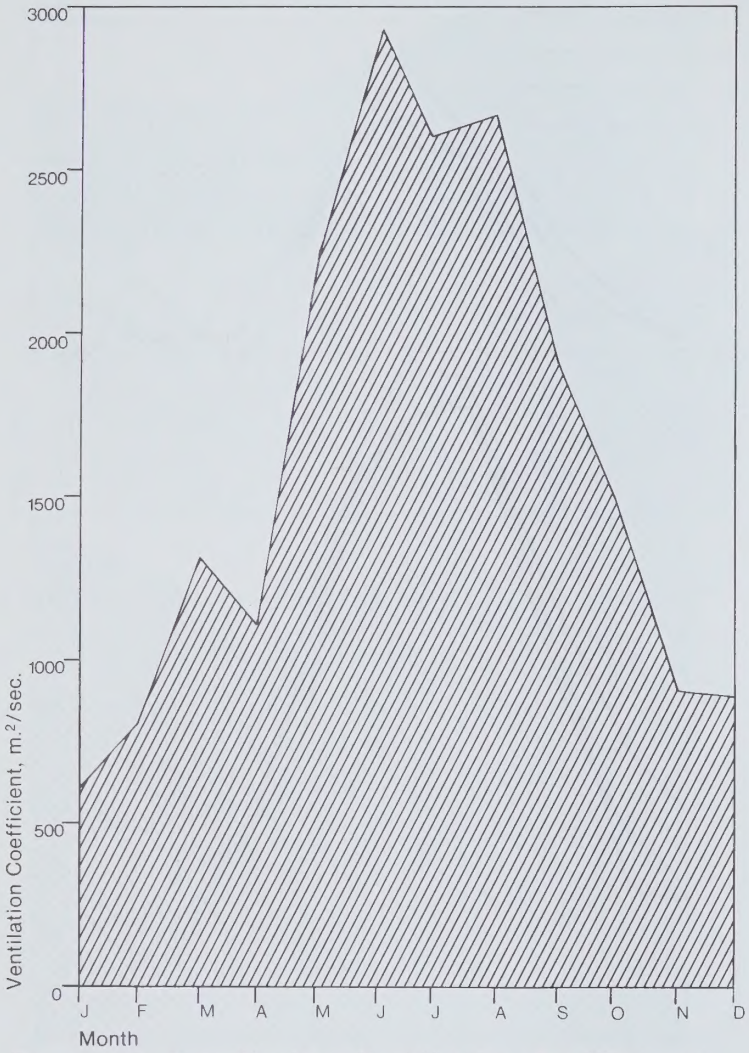


Figure 28 Mean Maximum Ventilation Coefficients For Resolute A

Ice Climatology

by W.J. Sowden

INTRODUCTION

Knowledge of the behaviour and characteristics of the ice in summer and winter and also of year-to-year variation in the pattern and timing of freezeup and breakup are required for planning and operational purposes. Unfortunately all the required data to determine the behaviour patterns, ice characteristics, and variations do not exist for all periods of the year. There are, however, approximately 20 years of ice-distribution data available for the May-to-October period to provide an accurate description. These are included in this report as well as a survey of the available data and calculated values for ice thickness and discussions on ice topography and icebergs. In conclusion, there is an outline of the areas in which there are insufficient data.

CURRENT ICE CONDITIONS

General Distribution of Ice

The attached charts use a number of different formats to show the ice distribution in Lancaster Sound and its surrounding area. Series A, B, and C show the maximum, median, and minimum amounts of total ice for the 17-year period, 1975-1974. "Total ice" is defined as the total amount of sea ice of all types (ages) but does not include icebergs.

The favoured location of the eastern edge of the consolidated ice is between Barrow Strait and Lancaster Sound (near 90°W). The other locations for the edge of the consolidated ice are at 83°W and near 81°W in eastern Lancaster Sound and in western Barrow Strait at 95°-96°W. The reason for these three basic locations has not been completely detailed as yet but are no doubt due to specific combinations of water currents and meteorological parameters, mainly wind and temperature, at freezeup time.

During winter months the ice consolidates (fast ice) in the western portion of Lancaster Sound while in the eastern portion, although

remaining at mostly 100 percent cover, it does not, with the occasional exception, become consolidated. During May some looseness occurs or an open-water area develops along the southern Devon Island area (east of the fast-ice edge) or open water develops at the eastern edge of the fast ice. As the loosening and melting of the ice continues and concentrations start to decrease they do so in such a way that the concentrations remain higher on the south side of the sound. With increased melting, the open-water area normally develops on the north side and at the same time the north water area of northern Baffin Bay increases in area southwards along the western side of the bay until it joins up with the open-water area of northern Lancaster Sound. This sequence of events is normally completed by mid-June, after which continued clearing on the south side of the sound takes place through melting and the eastward movement of ice into Baffin Bay.

The consolidated or fast-ice cover in the western sound is considerably slower to decay and breakup. Melting and fracturing does occur over large areas, which leads to decreased concentrations and some motion along the south side of the sound. In the absence of strong winds to assist in its motion, the large areas of gradually decreasing concentrations remain in place until the ice melts completely. The sound is then clear of ice during the summer months with the exception of intrusions from two locations. In September the ice from Kane Basin moves south along the Ellesmere Island and Devon Island coasts and, during some but not all years, it intrudes around the southeast corner of Devon Island and into the entrance of the sound, though seldom does it reach as far west as Croker Bay. As the supply of ice from the Smith Sound and Kane Basin decreases and as freezeup commences, the ice intrusion is either dispersed and melts or, in some cases, remains to become part of the following season's ice cover.

The other intrusion that occurs takes place from the west as the ice from Barrow Strait moves eastwards, normally but not always through the southern half of the sound, after breakup in Barrow Strait has occurred. This ice is normally first-year ice but on rare occasions small concentrations of second-year or even multi-year ice from Viscount Melville Sound may be briefly present.

Freezeup has normally occured by mid-October after which the ice thickens and the area of

consolidated ice is established, normally during late December or by mid-January.

The above describes the general sequence of events as defined by the median pattern of breakup and freezeup (see Figures 13-24). However, many variations within this pattern take place both in time and in distribution. However, before considering year-to-year variations, it is necessary to consider ice thickness, such topographical features as ridging and hummocking, and the occurrence of icebergs.

Ice Thickness

Seasonal total freezing degree day (FDD)* accumulations average approximately 5 400 FDDs (°C) but vary in range from 5 000 to 6 300 FDDs (°C). These are slightly higher in the west and less in the eastern entrance of Lancaster Sound. Using these accumulations, the calculated ice thickness at maximum ice growth is from 177 cm to 203 cm, with the average being 180 cm. This is somewhat more than the thicknesses arrived at in estimates of the ice thickness range for the sound, based on limited shore station reports. Those estimates show thickness for the eastern section of the sound to be 110 cm to 180 cm with an average of 140 cm, while in the west section the range is 140 cm to 200 cm and the average of 170 cm. Actual on-ice measurements are scarce; those that do exist support the latter figures for first-year ice whose growth has been continuous from the on-set of FDDs. Of course, large sheets of thinner ice occur even during June when maximum ice thickness usually occurs (maximum accumulation of freezing degree days). These are areas that due to wind stress, especially if supported by water stress, have developed wide leads or temporary polynya then refreeze with ice growth thickness consistent with the FDD accumulation commencing on the refreezeup date.

The amount of multi-year ice-thickness measurements in Lancaster Sound are very limited and the calculated-thickness method is not usable because the number of melt-growth cycles is normally not known nor is the amount of growth-melt. During the Manhatten's passage in October 1969, measurements of 180-270 cm and 210-300 cm were obtained. However, other reports of up to 480 cm are on record but it is not known if these are for undeformed ice or whether ridging or other effects of ice under stress had occurred.

Considering the evidence from the calculated methods and based on measurements, either from

* e.g. Using 0°C as the base, if the mean daily temperature is -5°, there are 5 FDDs for that date.

shore stations or on-ice measurements, ice thickness of up to 180 cm for first-year ice is to be expected, with somewhat thinner ice on the north side of the sound, and thicknesses of up to 340 cm for multi-year ice. Ice thicker than the multi-year does exist but it is no doubt due to deformation as discussed in the following section.

Ridging and Hummocking

The upper surface topography of the ice in Lancaster Sound has not been documented sufficiently to allow a detailed description of it to be given and there has been no investigation into the character or dimensions of the under surface. However, because there is considerable motion of the ice during its early growth period and because it is subject to wind and water stresses throughout its existence, deformation does take place and remains as long as the ice exists.

The measurements and evidence that do exist support the generally accepted theory that when ridging and hummocking is formed, mostly early in the season, it remains with little change until it decays during breakup. It is difficult to estimate the frequency of ridges, but in general, there are six to ten ridges per kilometre with heights of 0.6 to 1.4 m in the first-year ice. There are specific areas where the frequencies and heights can be expected to be greater, such as along the shear zones near the edge of the land-fast ice and perhaps to a lesser extent along the edge of the consolidated ice in the western sound. There are also higher frequencies of ridging reported near the Bylot Island exit area. The consolidated ice has been reported to be well ridged during some seasons with up to 50 percent of its surface ridge- covered.

Since there is normally very little multi-year ice in the sound, little investigation of its dimensions has been carried out. What evidence is available indicates ridge frequencies are higher on multi-year floes and heights are in all probability also higher.

Icebergs

The icebergs that affect Lancaster Sound almost exclusively originate in the land areas surrounding parts of Baffin Bay, mainly eastern Baffin Bay from the Disko Island area northward to Melville Bay. The icebergs are moved on a westward trajectory by current and winds and some reach the sound's entrance. Their motion is

basically controlled by currents but the effect of wind will add to or alter their movement. Very few bergs are thought to originate in the archipelago and it is unlikely these affect the sound. However, in the early 1960s ice island fragments are known to have existed in Viscount Melville Sound and Barrow Strait and it is possible that a few of these may have reached Lancaster Sound. At the present time (1979) there are no fragments posing a threat to the study area.

VARIABILITY IN ICE CONDITIONS

General Distribution of Ice

In the attached charts "maximum ice cover" is defined as the area where ice has existed at least once during the 17-year period 1958-1974. The highest concentration when ice occurs more than once is that shown on the chart. The "minimum ice cover" charts show the areas where ice has always been reported on the date indicated; for example, if an area on 25 June chart is 40 to 60 percent of ice, this is interpreted as meaning that on that date during the period 1958 to 1974 there has always been at least 40 to 60 percent of ice present. The "median ice" position is simply the average position and concentration (statistically) of the total of all ages of ice for any particular date.

As can be seen on the maximum ice charts (Figures 1-12), there is only a very small area in Lancaster Sound that did not have ice at least once. In contrast to this, the minimum ice chart shows very little ice until the latter half of October (Figure 36).

Series B, the median ice charts (Figures 13-24), show the pattern of breakup and freezeup although there are year-to-year variations. The movement of ice from Kane Basin along Ellesmere and Devon islands can be seen occurring on the 17 September and 1 October charts of Series B (Figures 21 and 22). However, since there is a high concentration of old ice in Kane Basin it can be seen better on the maximum for old ice chart for 17 September (Figure 49). This chart shows a very heavy concentration of old ice while the median chart for old ice (Figure 45) does not show this intrusion since its old ice concentration is not always high nor does it occur every year.

Ice Thickness

There is a variation in the period when ice would continue to grow; that is, in the dates of the beginning and end of the freezing degree day (FDD) period. For the Lancaster Sound area, FDDs begin to accumulate, on the average, on 8 September for the western end and 15 September for the eastern entrance. There is a wide variation, however, and FDD accumulation has occurred as early as 1 September and as late as 25 September. The end of the FDD period varies from 28 May to 2 July, with the average date being approximately 11 June. It is a little earlier in the east and later in the west.

Ridging and Hummocking

The major leads and polynya (open-water areas) in the Lancaster Sound have already been mentioned and are easily identifiable on the charts, (for example, see Figure 14). Most other such features are temporary in nature, opening and closing with variations in wind stress. However, there may be favoured locations for these, but as yet no study has been carried out to identify such areas. These may be significant for site specific operations and should be the object of further investigation.

Icebergs

A study of ice charts for the area from 78°W longitude to 92°W longitude in Lancaster Sound for the period 1958-1976 indicated that a little over 1 400 icebergs were reported. Because of the frequency and type of aerial reconnaissance, it is unlikely that this represents a true picture of the number of bergs that actually existed. However, if their percentage by geographical location is considered, the result is probably a statistically true representation of their density distribution. Table 1 shows their individual degrees of longitude.

Table 1

Longitude (W)	92	91	90	89	88	87	86	85	84	83	82	81	80	79	78
Percentage of Reported Bergs	<1	<1	<1	1	1	2	2	5	6	15	17	17	18	11	5

Considering water currents, which are thought to be basically westward along the north side of the sound and eastward along the southern side with some crossover taking place, then the population density shown in Table 1 is understandable.

Iceberg migration is greatest during the months of July to October when their motion is unimpeded by heavy concentrations of sea ice.

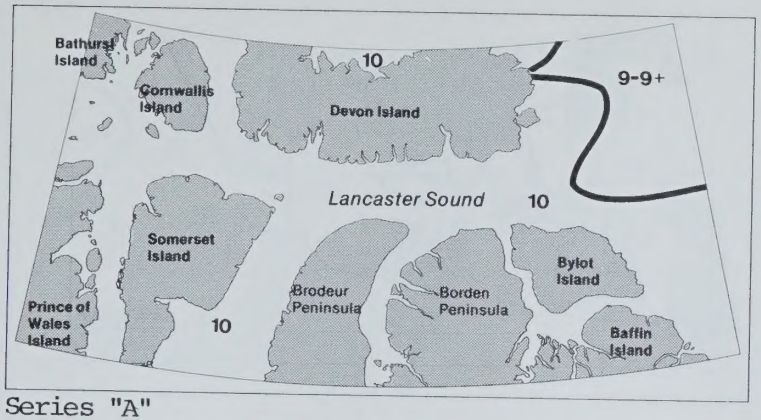
COMPLETENESS AND QUALITY OF DATA

The ice distribution in Lancaster Sound is well documented as to the amount, types, and growth and decay cycles during the May to November period. More documentation is required for these parameters for the December to April period. For site specific considerations, such as planning for harbours, analysis and summarization of various floe sizes during the various stages of development and decay are needed, as is a study of shore-fast ice.

Actual measurements of ice thickness either by on-ice measurements or remotely sensed thickness are required, as well as growth rates. In the report, a method of calculating ice thickness using freezing degree day accumulation is mentioned. However, verification of these results is required.

The acquisition and analysis of remotely sensed upper and lower surface topography of such features as ridges, rafting, and hummocking is necessary so that these features can be more fully described and their effect determined on various activities which might be undertaken.

Finally, the amount of data on the number, size and trajectories of icebergs is very limited. This subject should be included in future data gathering systems or projects.



Series "A"

Figure 1 MAXIMUM TOTAL ICE May 28

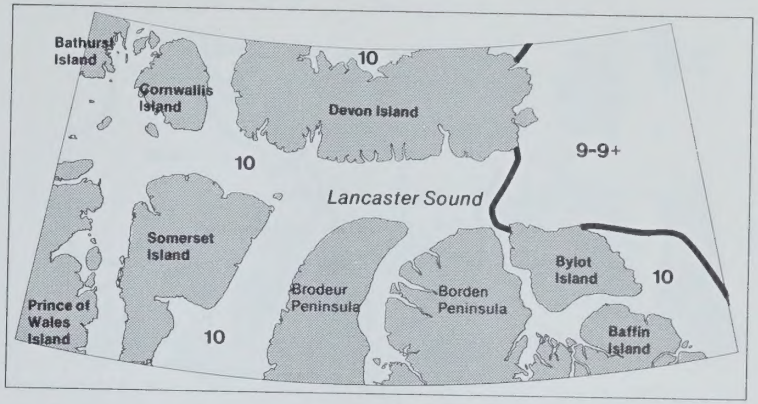


Figure 3 MAXIMUM TOTAL ICE June 25

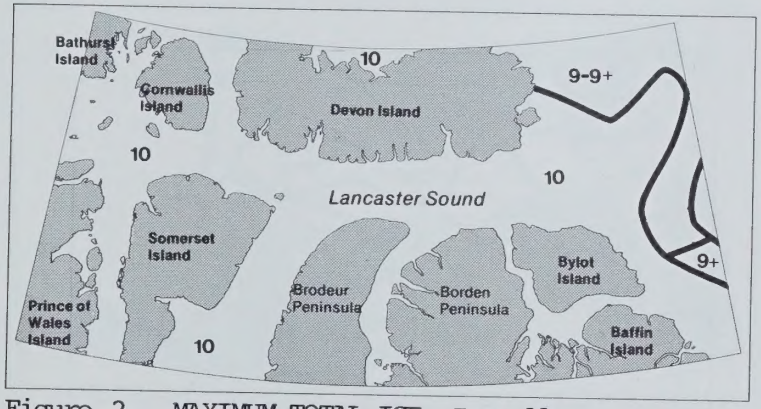


Figure 2 MAXIMUM TOTAL ICE June 11

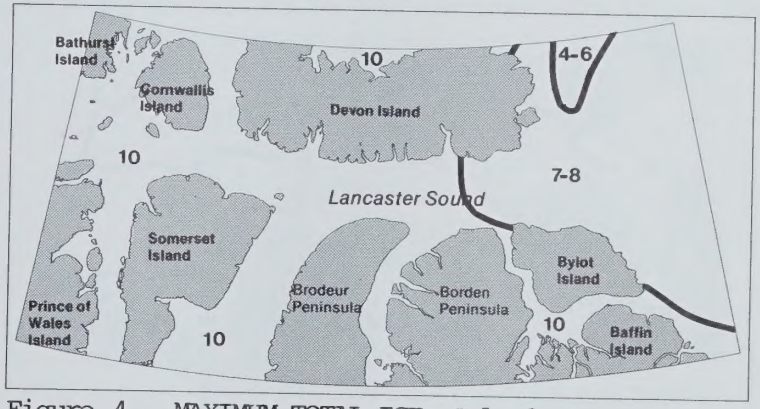
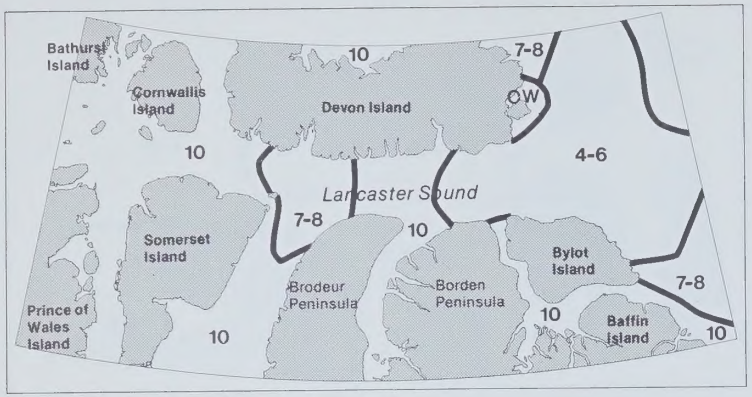


Figure 4 MAXIMUM TOTAL ICE July 9



Series "A"
Figure 5 MAXIMUM TOTAL ICE July 23

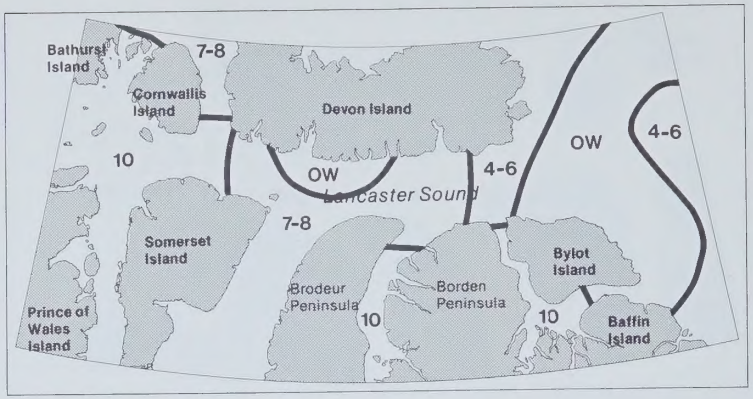


Figure 7 MAXIMUM TOTAL ICE August 20

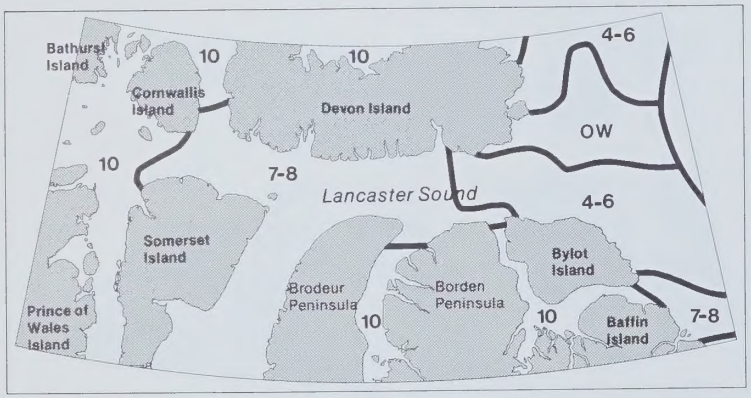


Figure 6 MAXIMUM TOTAL ICE August 6

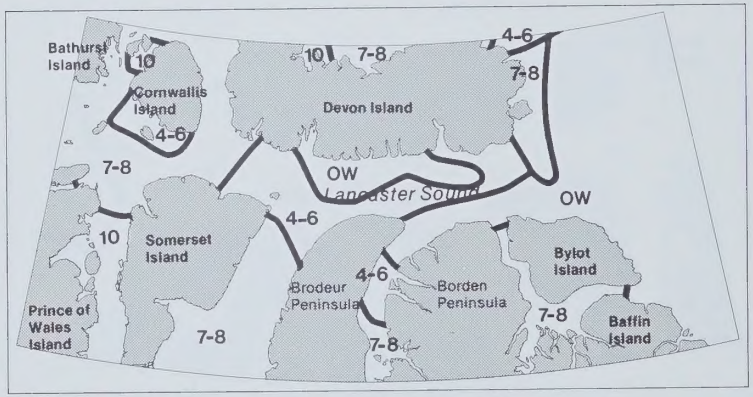
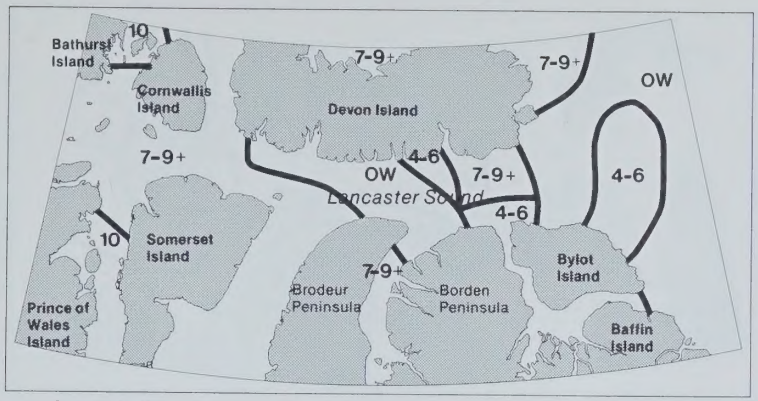


Figure 8 MAXIMUM TOTAL ICE September 3



Series "A"
Figure 9 MAXIMUM TOTAL ICE September 17

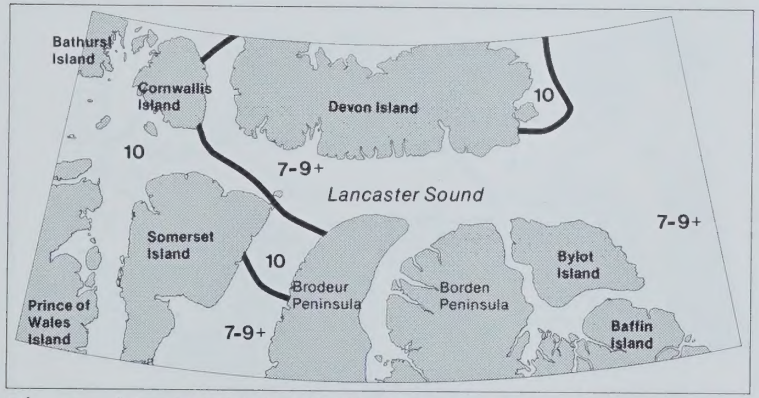


Figure 10 MAXIMUM TOTAL ICE October 1

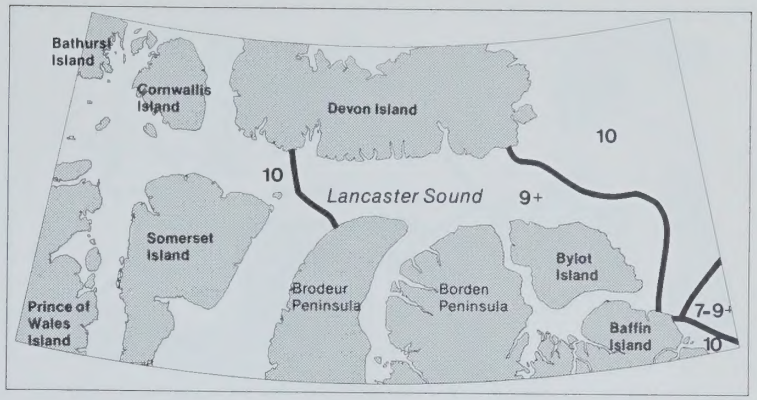


Figure 11 MAXIMUM TOTAL ICE October 15

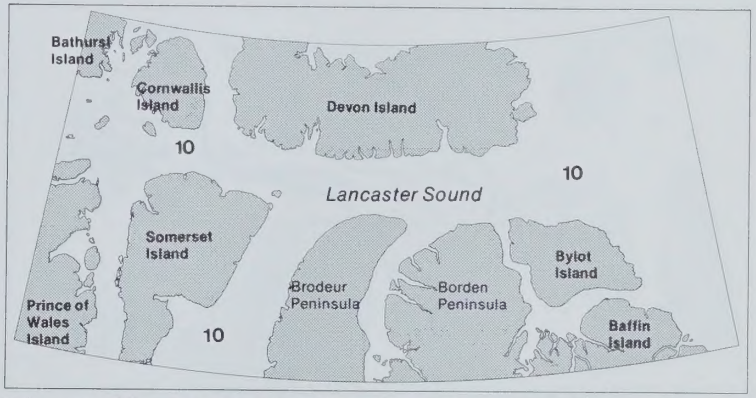
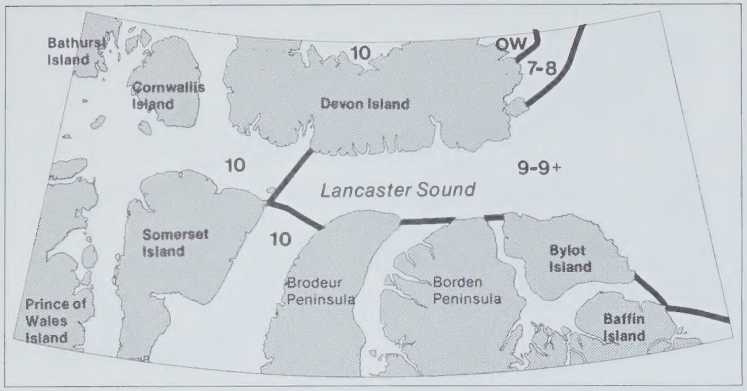


Figure 12 MAXIMUM TOTAL ICE October 29



Series "B"
Figure 13 MEDIAN TOTAL ICE May 28

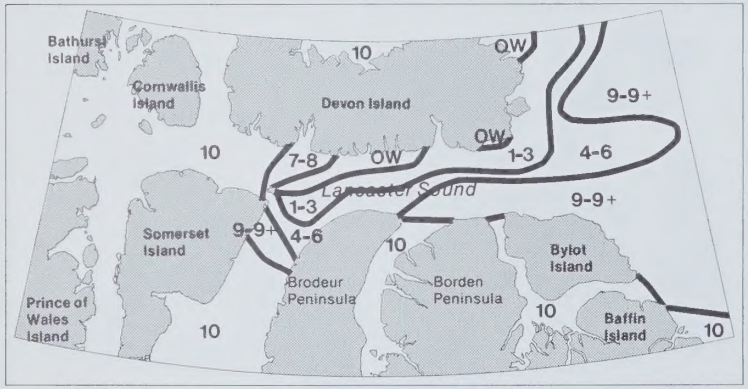


Figure 14 MEDIAN TOTAL ICE June 11

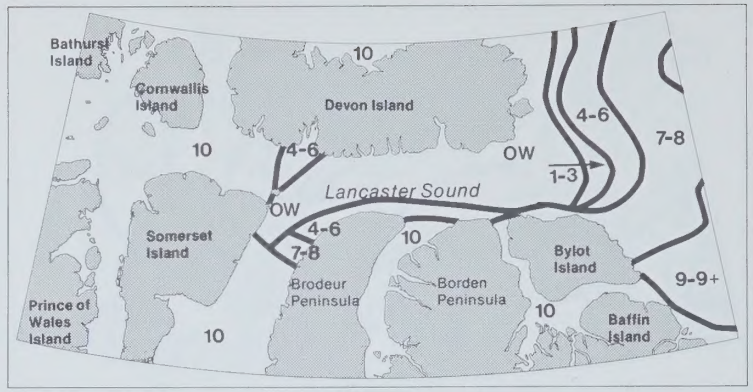


Figure 15 MEDIAN TOTAL ICE June 25

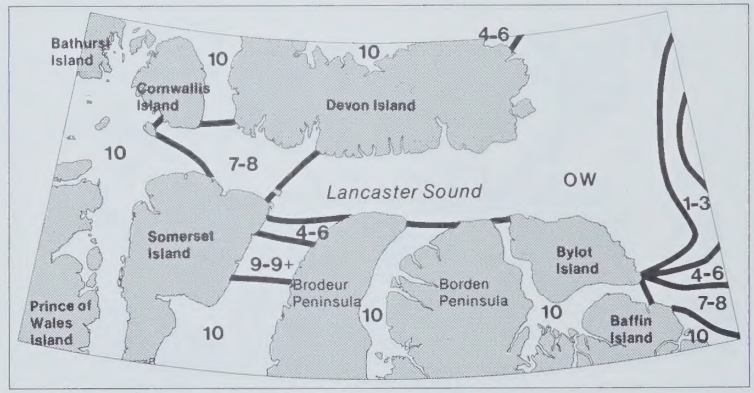
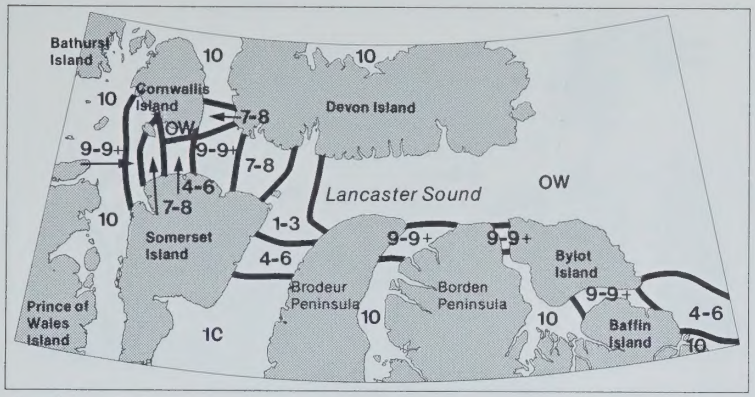


Figure 16 MEDIAN TOTAL ICE July 9



Series "B"
Figure 17 MEDIAN TOTAL ICE July 23

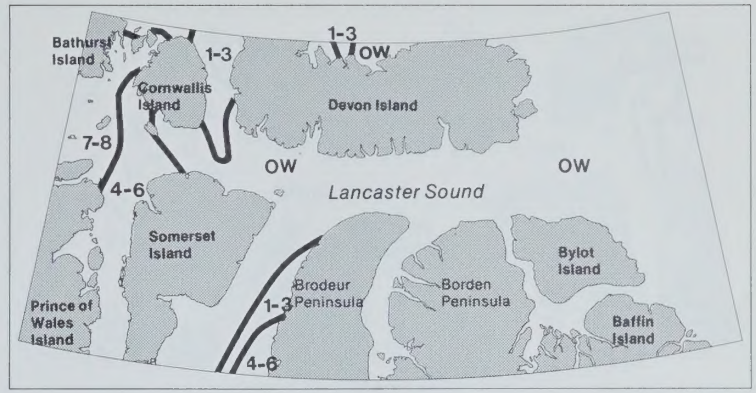


Figure 19 MEDIAN TOTAL ICE August 20

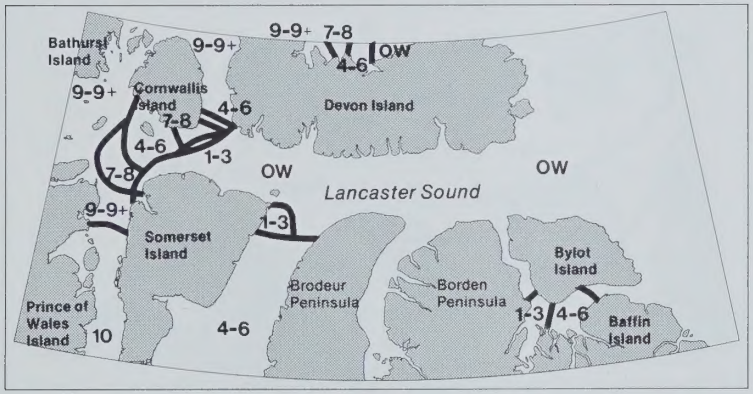


Figure 18 MEDIAN TOTAL ICE August 6

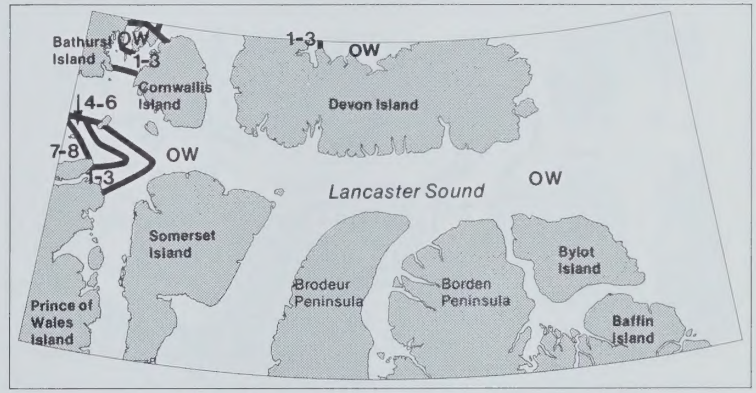
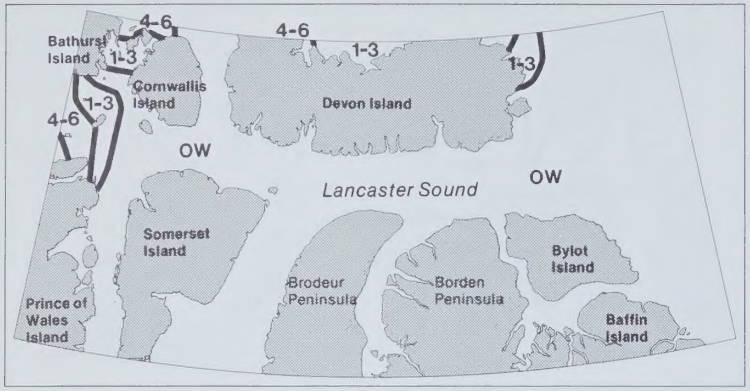


Figure 20 MEDIAN TOTAL ICE September 3



Series "B"
Figure 21 MEDIAN TOTAL ICE September 17

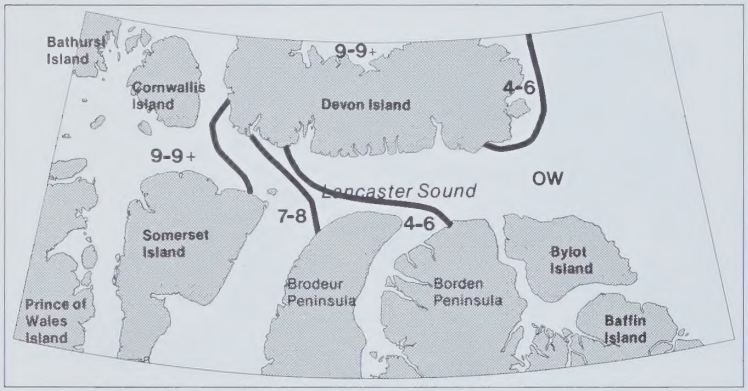


Figure 22 MEDIAN TOTAL ICE October 1

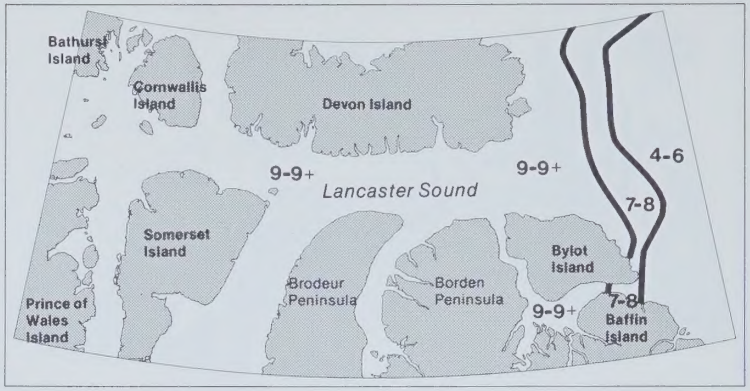


Figure 23 MEDIAN TOTAL ICE October 15

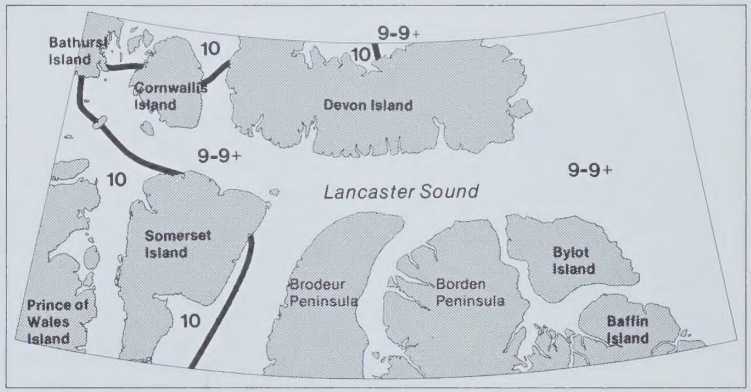
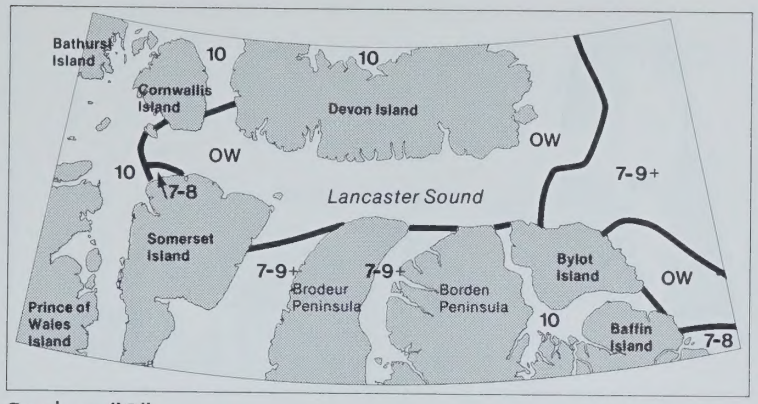


Figure 24 MEDIAN TOTAL ICE October 29



Series "C"
Figure 25 MINIMUM TOTAL ICE May 28

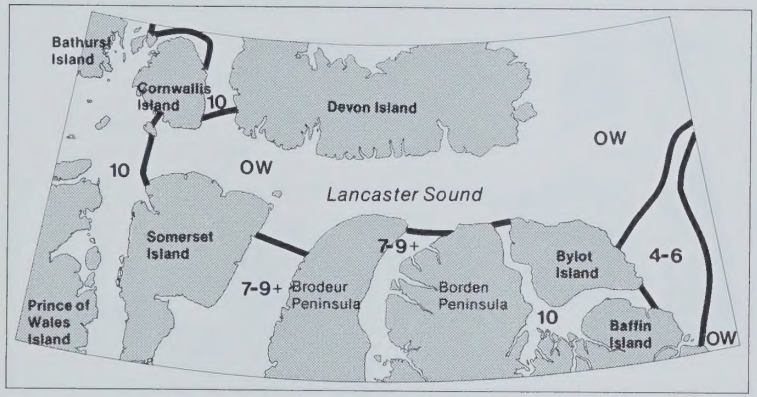


Figure 26 MINIMUM TOTAL ICE June 11

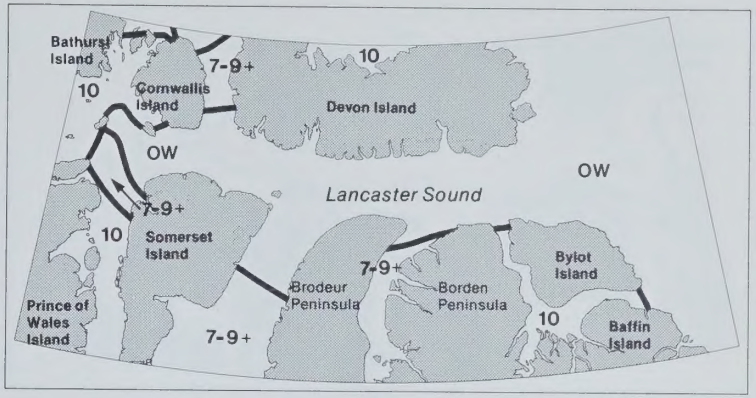


Figure 27 MINIMUM TOTAL ICE June 25

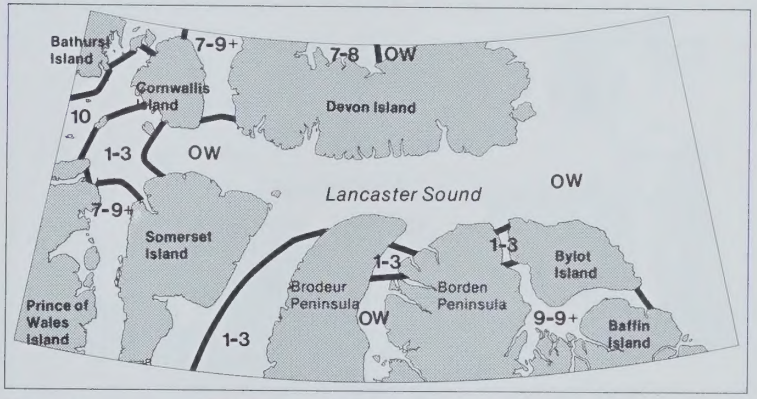
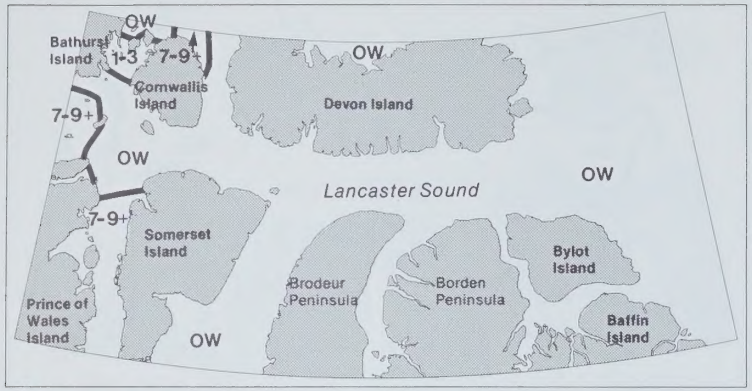


Figure 28 MINIMUM TOTAL ICE July 9



Series "C"
Figure 29 MINIMUM TOTAL ICE July 23

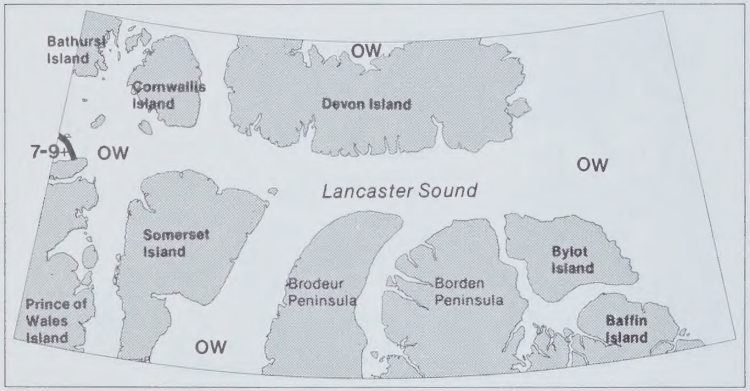
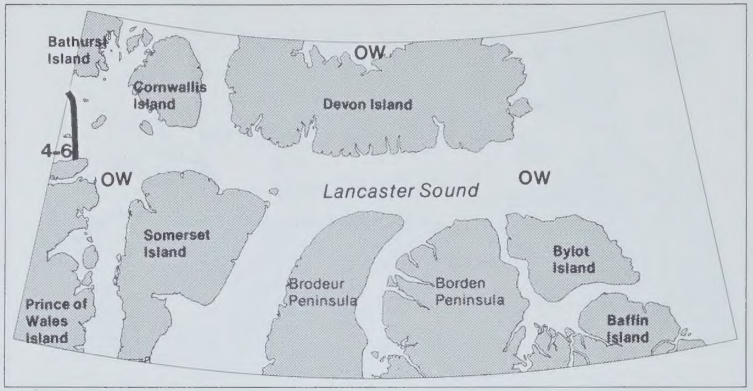


Figure 30 MINIMUM TOTAL ICE August 6



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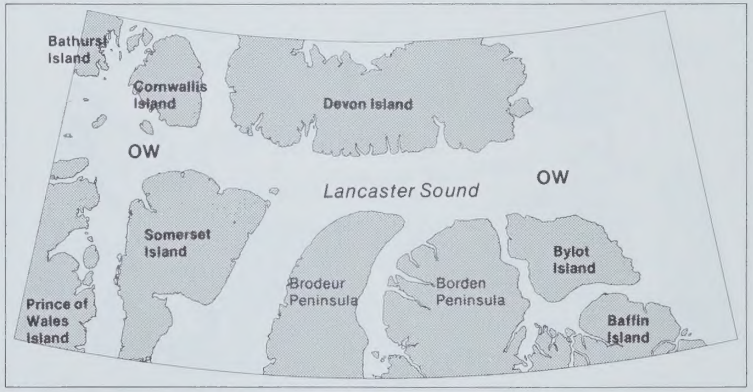

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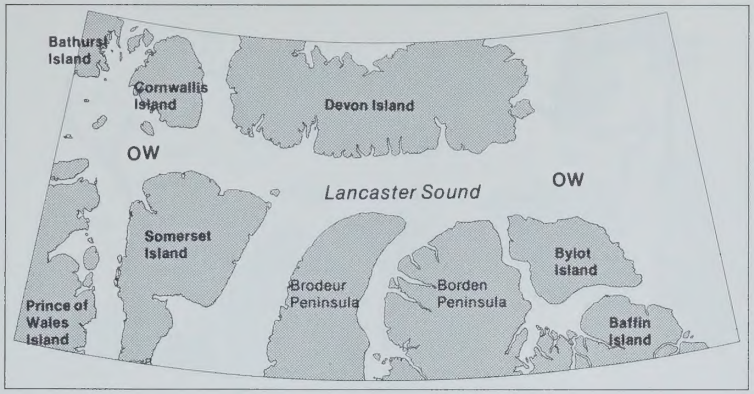


Series "C"
Figure 33 MINIMUM TOTAL ICE September 17

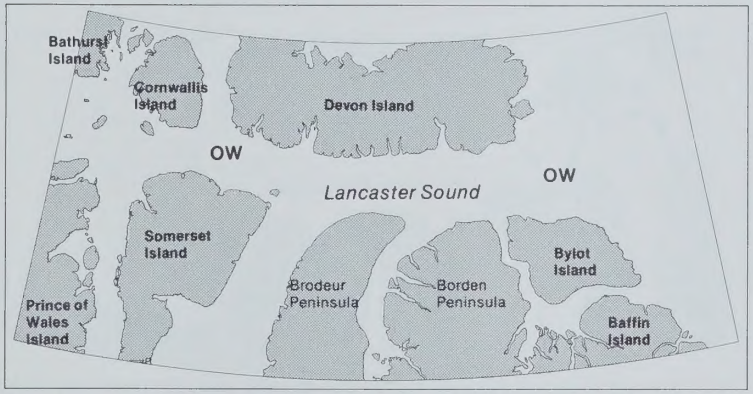
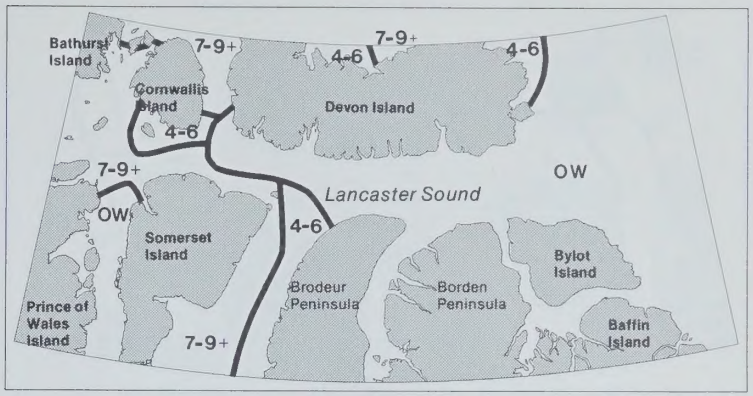


Figure 34 MINIMUM TOTAL ICE October 1



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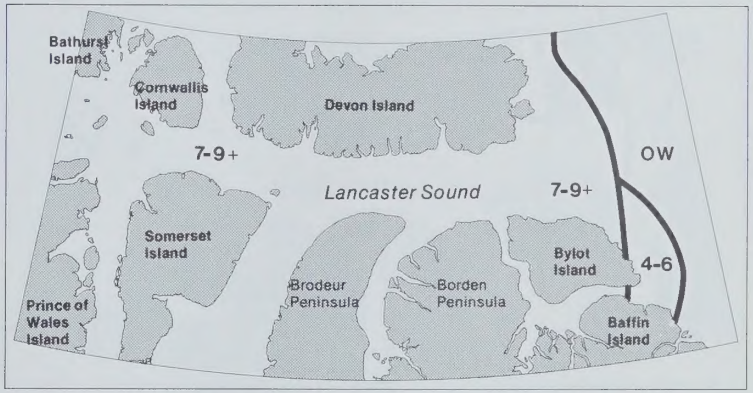
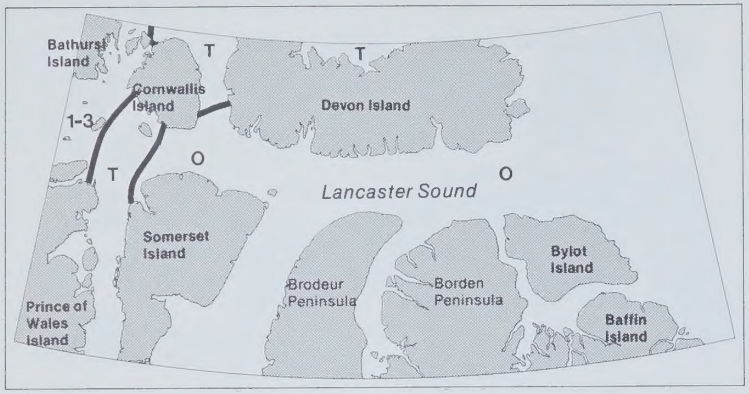


Figure 36 MINIMUM TOTAL ICE October 29



Series "D"
Figure 37 MEDIAN OLD ICE May 28

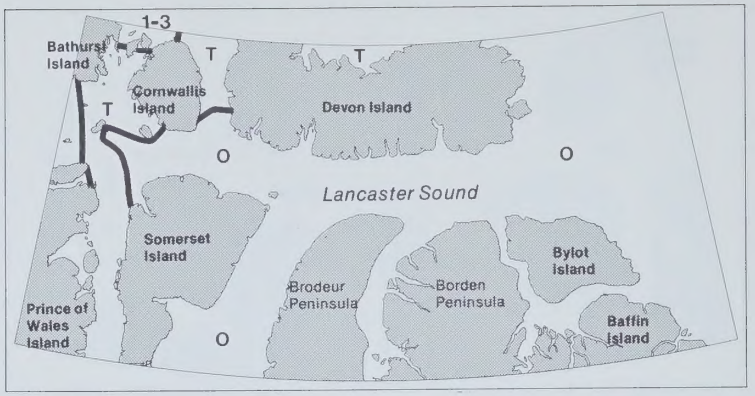


Figure 39 MEDIAN OLD ICE June 25

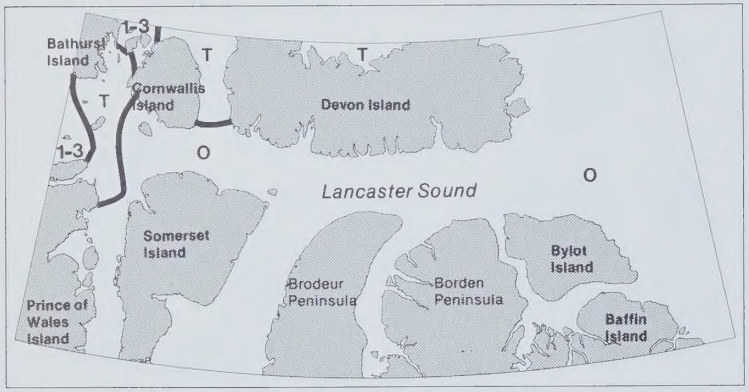


Figure 38 MEDIAN OLD ICE June 11

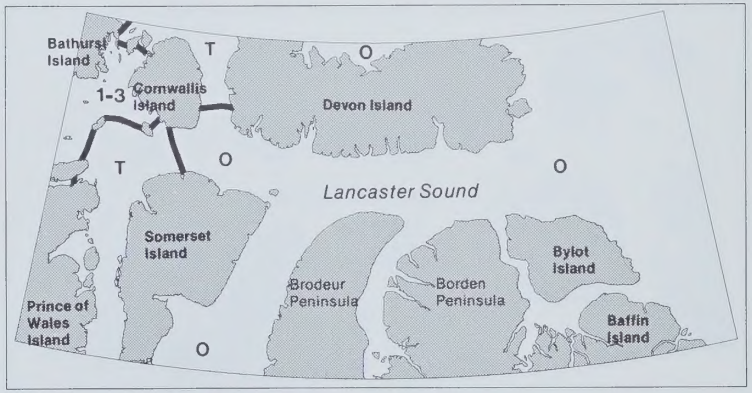
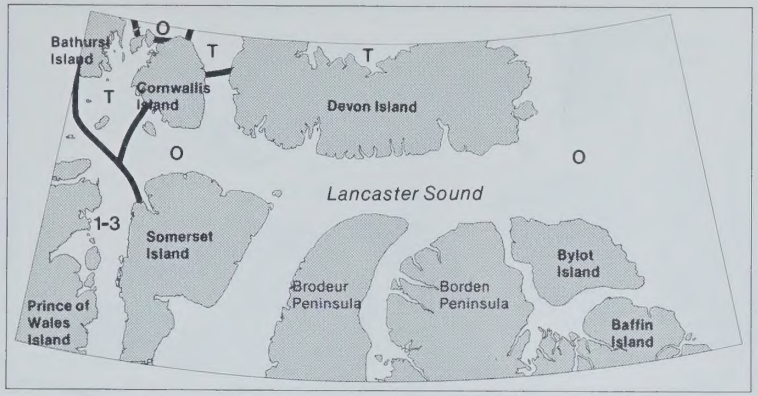


Figure 40 MEDIAN OLD ICE July 9



Series "D"
Figure 41 MEDIAN OLD ICE July 23

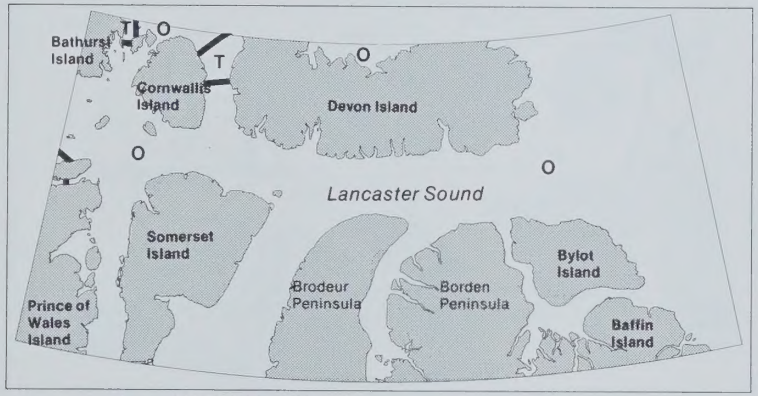


Figure 42 MEDIAN OLD ICE August 6

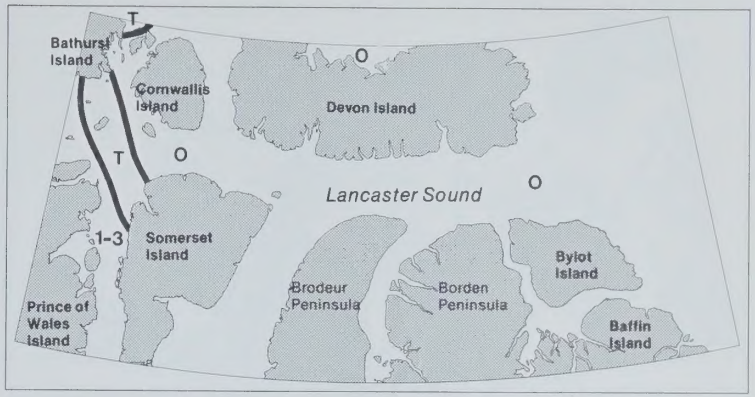


Figure 43 MEDIAN OLD ICE August 20

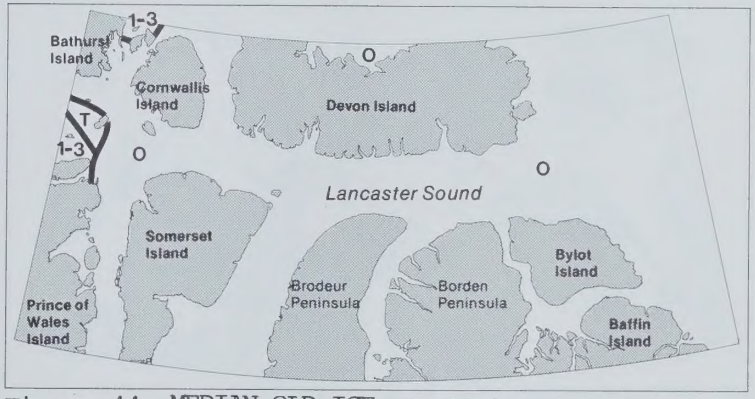


Figure 44 MEDIAN OLD ICE September 3

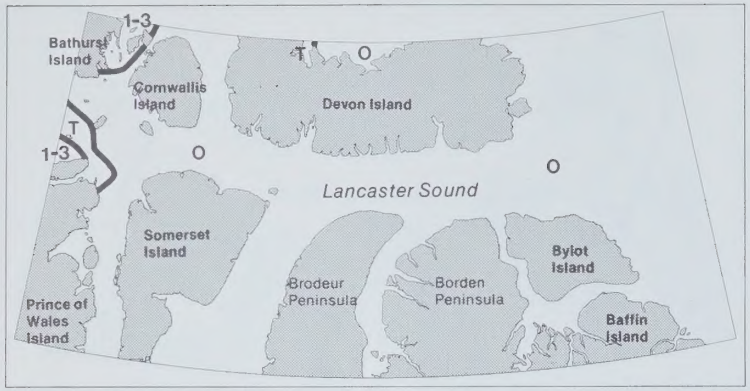


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Figure 45 MEDIAN OLD ICE September 17

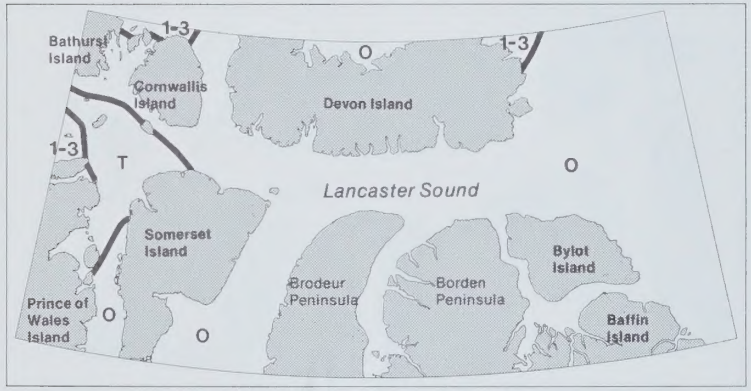


Figure 46 MEDIAN OLD ICE October 1

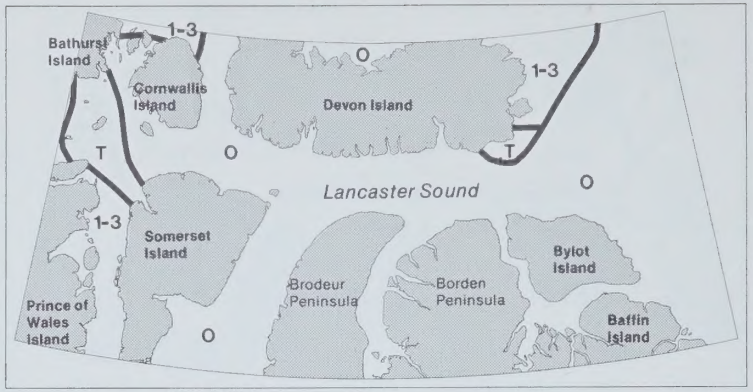


Figure 47 MEDIAN OLD ICE October 15

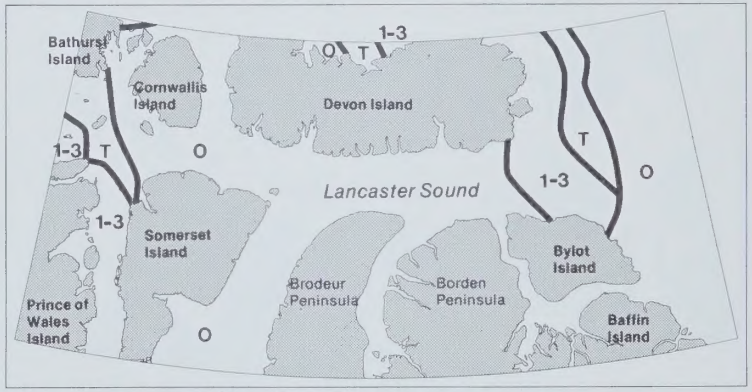


Figure 48 MEDİAN OLD ICE October 29

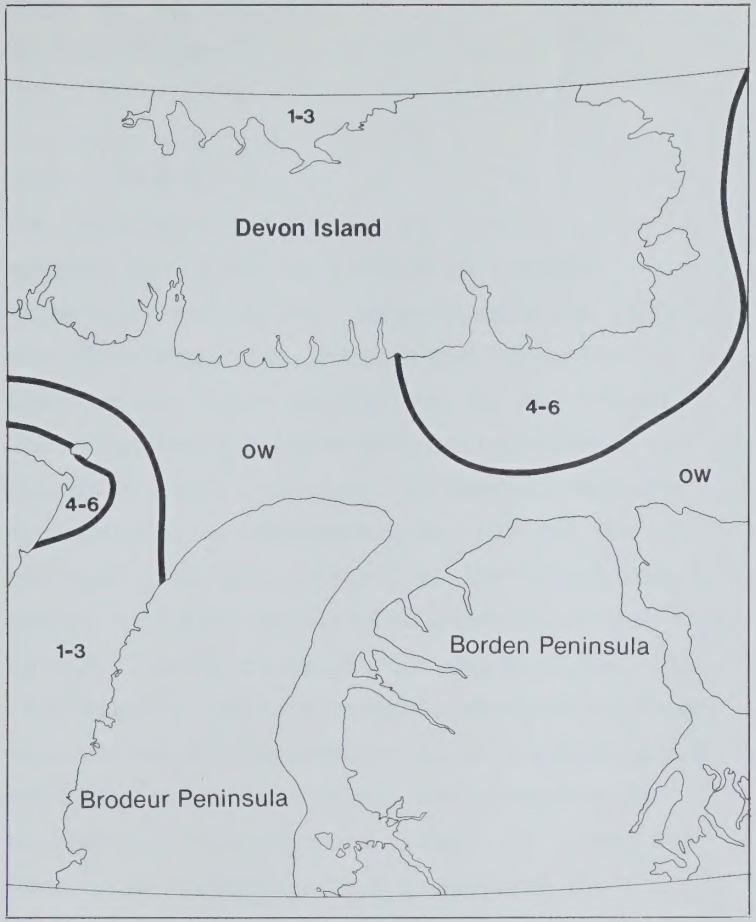


Figure 49 MAXIMUM OLD ICE September 17

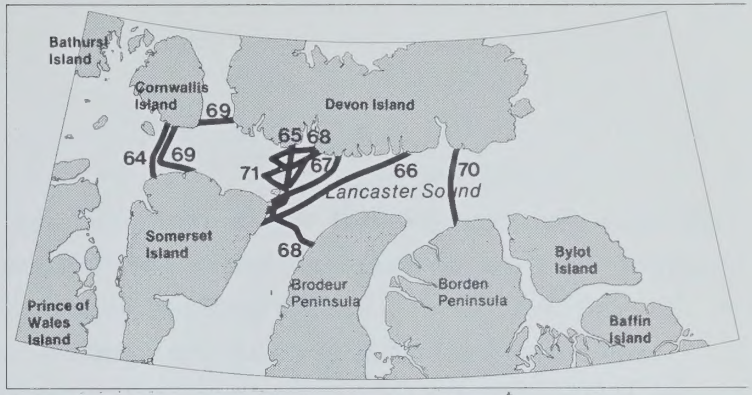


Figure 50 Series "G" CONSOLIDATED ICE EDGE 1964-1971

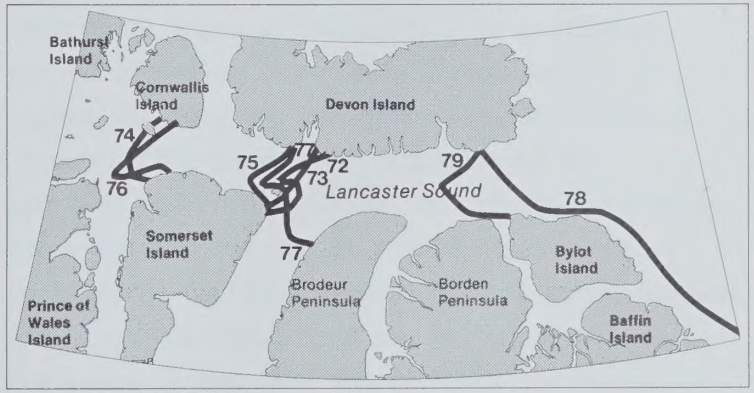


Figure 51 CONSOLIDATED ICE EDGE 1972-1979

Physical Oceanography

by B.D. Smiley

JUSTIFICATION

For this report, the scope of physical oceanography includes bathymetry (bottom topography and depths), water masses and their defining properties, surface and subsurface circulation, water levels, sea ice and icebergs. These fundamental oceanographic features of the Lancaster Sound region are portrayed, wherever appropriate, as constraints and hazards for offshore industrial activities, driving forces of marine pollution or features of wildlife survival. Detailed descriptions of, for example, the tidal constituents based on harmonic analyses or power spectral densities computed from temperature and salinity are not attempted, nor necessary for purposes of this regional study. Of necessity, some broad topics are thus treated in an elementary manner.

This rather simplistic approach has pitfalls; 'variability', in time and place, is the best one-word description which suitably characterizes the Sound's oceanography. Means of current speed and direction, ice or iceberg drift are sometimes misleading because the extremes are wide ranging and usually unpredictable.

There are some valid justifications for carefully addressing oceanographic features in a regional study of the Sound. For example, bathymetry is critical to the choice of safe shipping corridors, and the selection of harbours or feasibility of subsea oil/gas completion and pipelines. Water depth also dictates drilling strategies (dynamic positioning of drillships, design of marine riser) or, in the case of a subsea blowout, the behavior, fate and ultimate impact of the pollutant (formation of gas hydrates, oil droplet size, and residence time in water column, and so on). On a broader scale, bathymetric features such as coastal configuration and seabottom topography can strongly influence the water circulation and exchange through Lancaster Sound; for example, strong, nearshore currents align with the trend of the southern

Devon coast. Baffin water masses or layers are effectively barricaded by an elevated seabottom sill called the Barrow Strait shelf, near Prince Leopold Island. Icebergs are grounded by the under-sea pinnacles and shoals at the mouth of Navy Board Inlet. Near-surface currents control, to a large degree, the movements of sea ice, icebergs and, in the unfortunate event of an accidental oilspill, the spread of the pollutant. Sea ice is the fundamental constraint to man's and indeed wildlife's year-round presence in Lancaster Sound and vicinity. (A detailed treatment of sea ice types, distribution and breakup/freezeup patterns is provided by Sowden (1980)). The relatively long 'open water' season of the Sound is alluring to offshore industrial activities, yet the unpredictable and frequent intrusion of heavy ice floes and icebergs pose a real hazard to drilling shipping.

In a dynamic, open-ended oceanographic system such as the Lancaster Sound, general water circulation through the waterway is a rough indication of the 'downstream' threats from water-borne pollutants such as oil. In any regional study, environmental implications must be addressed beyond the local confines of marine industrial activities. Lancaster Sound cannot be described, oceanographically, independent of the Sverdrup Basin and Arctic Ocean, nor of its major discharge body, Baffin Bay (whose surface waters themselves intrude many kilometres into the channel). Direct reference to such distant regions, places Lancaster Sound in an overall arctic setting, by underscoring its regional, national and international significance.

PRESENT KNOWLEDGE

Bathymetry

The major sources of bathymetric information are the Navigation Charts (#7212, 7220, 7292 and 7503) published by the Canadian Hydrographic Service. The updated "Natural Resource Series" (#M16 to M21) are the most detailed charts of bottom contours and water depths in Lancaster Sound. Such detail is difficult to transfer to a different mapping scale and projection, thus Figure 1 shows only selected depths (isobaths).

Lancaster Sound is relatively deep, having depths of 800 - 900 m at its confluence with Baffin Bay. The Sound gradually shoals to the

west. The deepest spot (1124 m) of any charted channel of the Archipelago is nearby, in Pond Inlet. In general, the 30 metre isobath lies within 1 km of the Sound's shoreline. About 10 km off Cape Byam Martin (NE Bylot Island), the water is over 1000 m deep. Depths of 350 m extend into Admiralty, Navy Board and Prince Regent Inlets. Deeper troughs of 750 m or more are major features of Eclipse Sound and Navy Board Inlet. Obviously such depths pose no grounding hazard or minimum draft constraints to marine shipping in the Lancaster Sound region. Deep sea exploration technology is presently capable of drilling for gas and oil in water depths of 1000 m or more.

Relatively deep water extends to the heads of most southern Devon inlets, for example, Croker Bay remains about 350 m deep, 14 km north of its entrance, and navigable waters probably exist to its headwater glaciers. Calving glaciers and limited wind/wave protection, not water depth, restrict anchorage here (Barrie et al 1978).

Lancaster Sound, a familiar shipping route for the past 150 years, is probably charted better than most passages north of Hudson Strait. Nonetheless complete soundings are sparse in the Sound's shallower coastal waters, and extend, in detail, no further west than Barrow Strait. Viscount Melville Sound and M'Clure Strait, (the western half of Parry Channel), are ice-free for only a few weeks each year, and are neglected during ship-borne hydrographic surveys. Most coastal margins of Lancaster Sound lack soundings. For example, a 120 km stretch of inshore water from Croker Bay to Philpots Island is uncharted within 4 km of shore.

The Sound's seabottom is gently tilted, about 0.1° to the west and eventually rises to a 140 m sill in W Barrow Strait. This is the effective minimum threshold depth of Parry Channel, as is clearly shown in an east/west longitudinal depth profile (Figure 2). Cross-section profiles reveal, in exaggerated vertical scale, the deep irregular U-shaped 'valley' of Lancaster Sound (see Pelletier 1980). The valley sides are steep (maximum of 26° along S. Devon Island) and uniform to almost the full depth of the Sound (Collin 1962). West of Brodeur Peninsula (northern Baffin Island), the Sound narrows and loses this broad U-shaped profile. At the Barrow Strait shelf, near Resolute, the coastal slope is more gentle,

only 1.5°, and the bottom relief moderate (about 50 m). It should be remembered that today's coastal morphology, bathymetry and bottom topography are often expressions of the Sound's geological history. Indeed, the configuration and features of all Archipelago channels including Lancaster Sound, may represent the remanent patterns of preglacial drainage.

Water Layers and Circulation

Scientific inquiry by oceanographers commenced in the Lancaster Sound area during the late 1800s. These expeditions were led by oceanographers intent on describing the water masses of Baffin Bay, their derivation and character in terms of salinity and temperature. The notable 1928 Godthaab expedition, together with several subsequent shipborne expeditions in the 1930's, provided the backbone data which demonstrated the cyclonic (anticlockwise) gyre of the Baffin Current, and its relationship to adjacent channels, including Lancaster Sound, resulting in net flow from the Arctic Ocean to Baffin Bay (Kiilerich 1939). From data collected on the HMCS Labrador cruise in 1954 among the Arctic Islands, Bailey (1957) classified the different water layers of the region, stressing that strong, variable currents complicated his classification task. Collin (1960, 1962, 1963), Collin and Dunbar (1964), and Muench (1971) summarized the knowledge of physical oceanography of the Lancaster Sound region. These and subsequent authors (Fissel and Wilton 1978) pointed out the inherent shortcomings of the classical procedure using seawater densities (known as the dynamic method) for calculating the Sound's ocean currents. This problem is particularly true in eastern Lancaster Sound, a high latitude region of weak vertical stratification and strong currents. Nonetheless some features of the Sound such as the entrance's large anticlockwise gyre, and the net eastward water transport, are very persistent and dominant, being roughly reflected by these historic computations of large-scale circulation currents (Figure 3).

Lancaster Sound, as a segment of Parry Channel, is a direct ocean link between Polar Basin waters (Arctic Ocean, Beaufort Sea) and Baffin Bay waters. Generally the Sound's surface currents are a complex, variable blend of Arctic

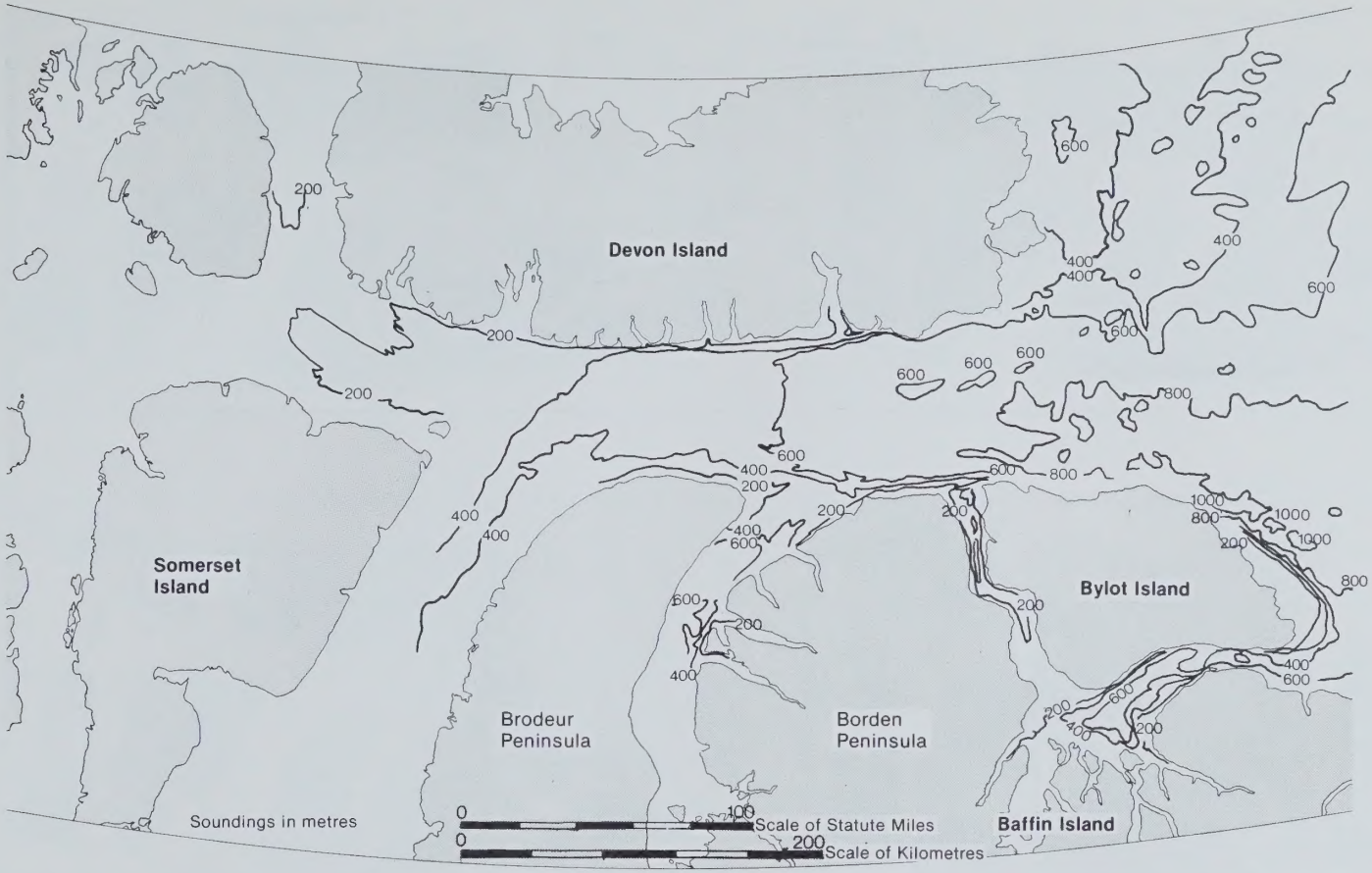
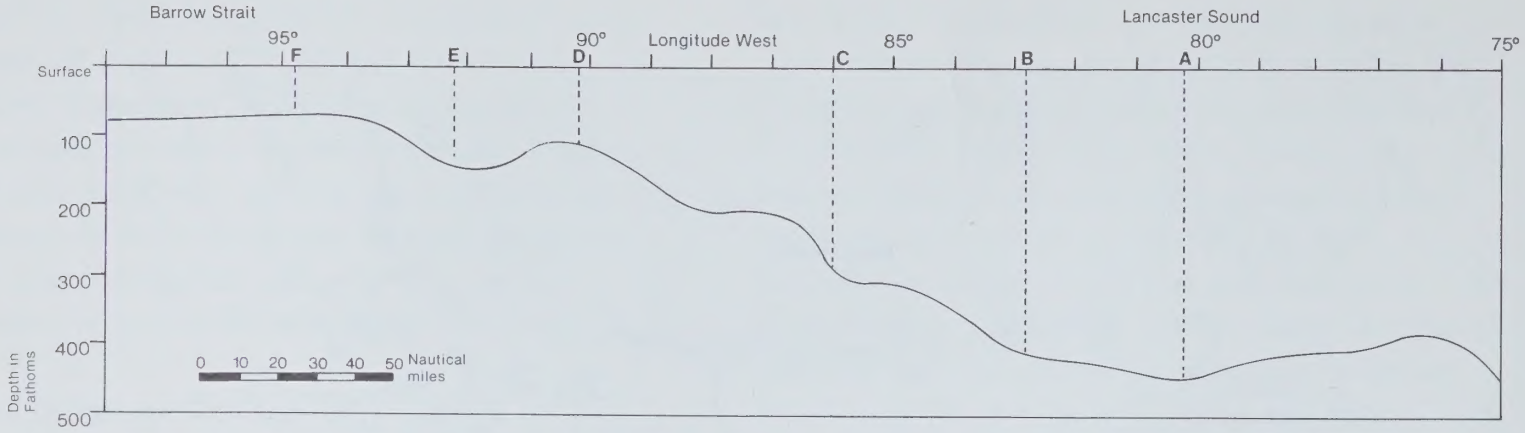


Figure 1 Bathymetry, Lancaster Sound & Approaches
(taken from Milne and Smiley 1978)



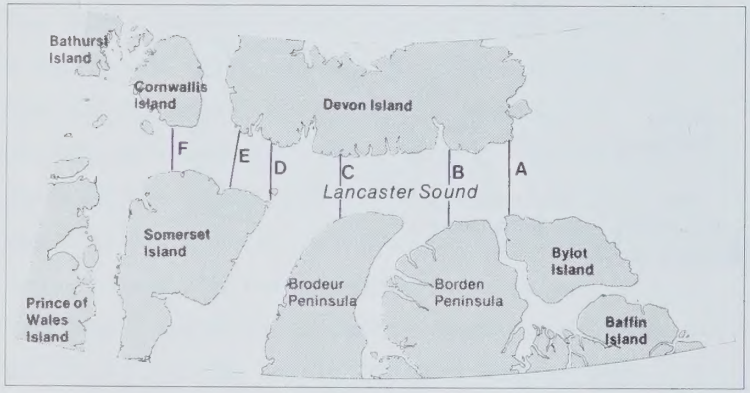
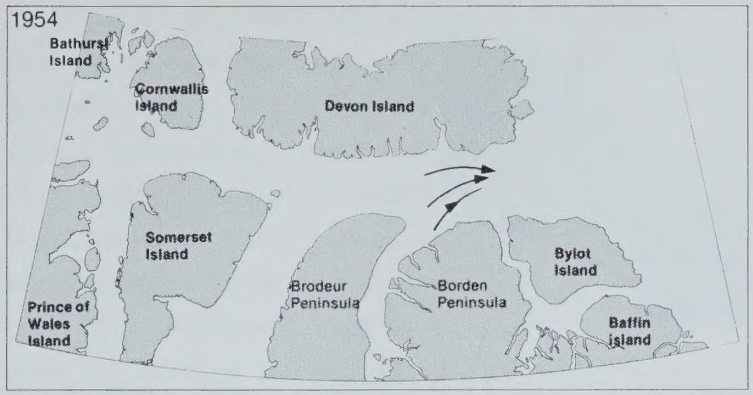
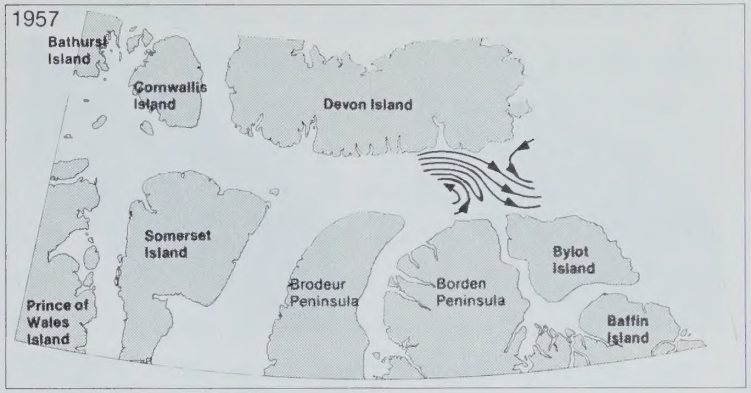
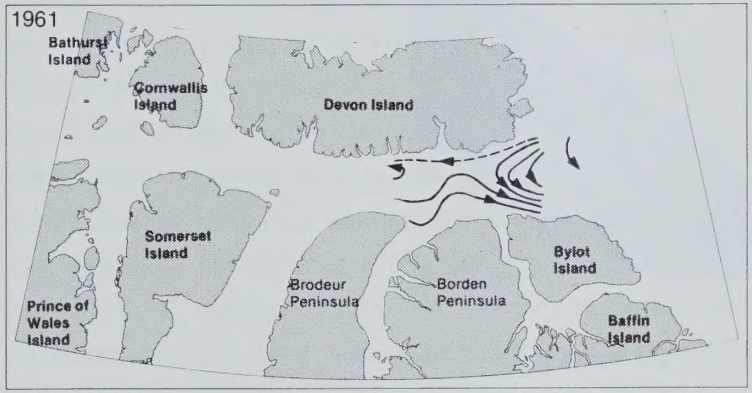


Figure 2 Longitudinal profile of Lancaster Sound and Barrow Strait (Collin 1962)







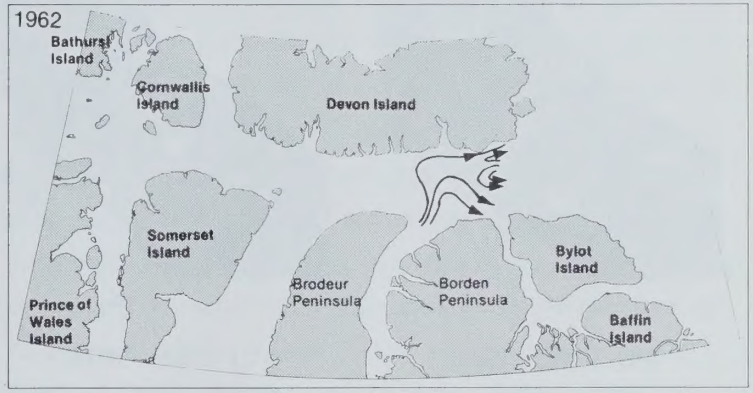


Figure 3 Summer patterns of surface currents computed by Meunch (1971) Note the annual variability

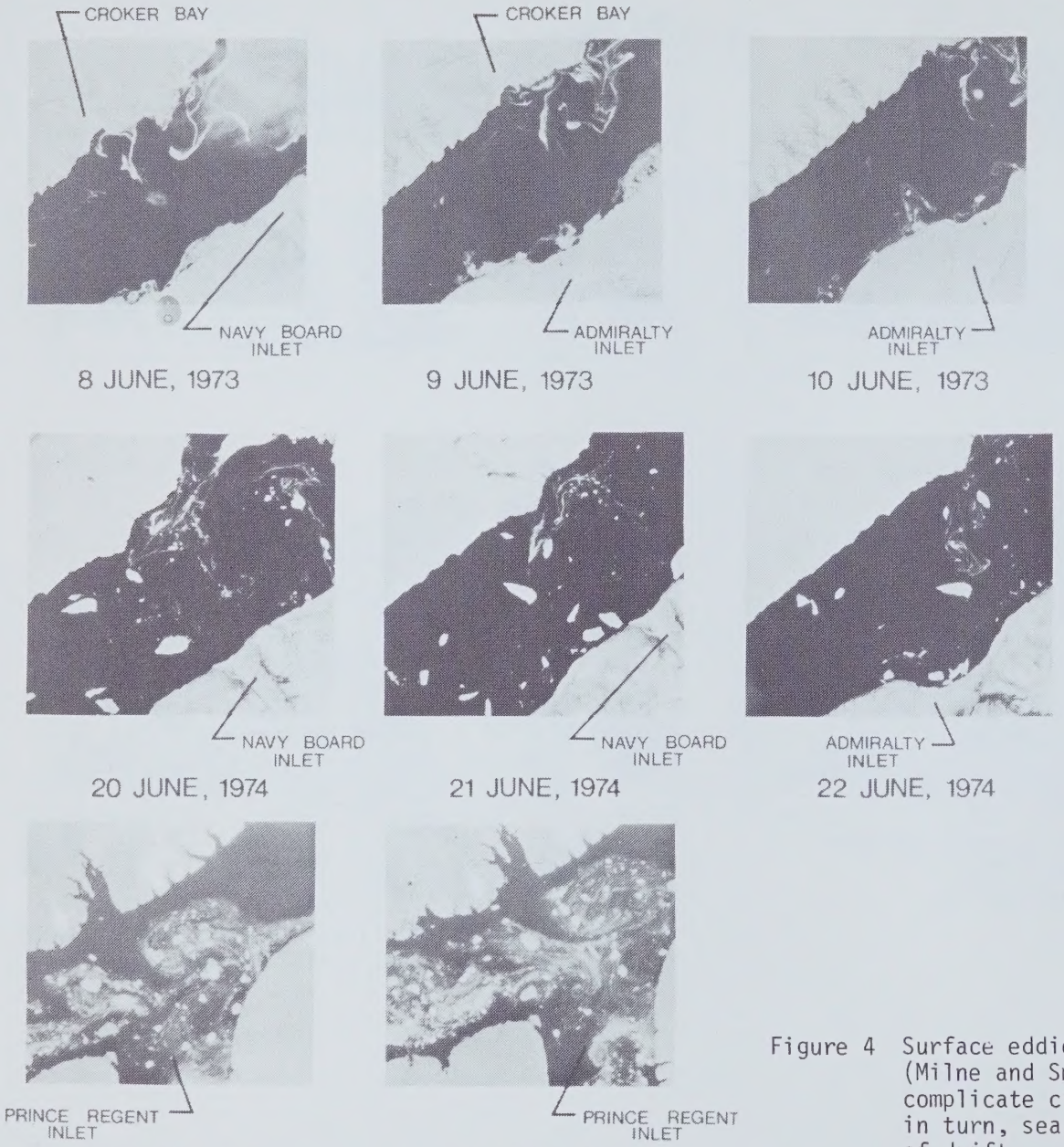


Figure 4 Surface eddies outlined by ice streams (Milne and Smiley 1978). These eddies complicate circulation patterns and, in turn, sea ice and iceberg predictions of drift.

Ocean water from west Parry Channel and several smaller Archipelago channels, and of Baffin Bay surface water. The latter is itself a mix of Arctic Ocean water from Smith and Jones Sounds with warmer, saltier West Greenland water. Together these water masses largely produce the water properties of Lancaster Sound.

This over-simplified picture of circulation does not account for eddies (Figure 4), gyres, return currents, deep water intrusions, tides and winds which alter current patterns and, to a lesser degree, water transport. As previously mentioned, a large, anticlockwise intrusion of Baffin Bay surface water is positioned at or near the Sound's east entrance, at least during the open water season. This giant, eddy-type feature, as evidenced by swift westward currents close to the southern Devon Island shore, permits the intrusion of surface Baffin Bay water, often laden with icebergs (Fissel and Wilton 1978). Although this current stream is usually less than 15 km wide it is speculated as penetrating 100 km or more into Lancaster Sound, and infrequently as far as Wellington Channel (Collin 1972; Greisman and Lake 1978). Eventually this prodigal current is mixed into the strong eastward (counter) flow of Arctic water out of Lancaster Sound, merging again with the Baffin Current along eastern Bylot and Baffin Islands.

The upper 250 m of the Sound are typically cold (-1.8 to 0.0°C) and low in salinity, less than 31 to 34.4 parts per thousand (°/oo) (Muench 1971). Extreme measurements are often recorded due to intense solar heating on calm summer days, freshing or chilling by seasonal ice melt, and mixing of surface (30-50 m) by strong winds or internal waves (Sekerak et al 1976). In contrast, the bottom waters deeper than 250 m or so are markedly warmer (0.0 to 2.0°C), and more saline (34.2 to 34.5 °/oo) and generally more uniform (Figure 5). These values closely mirror salinity and temperature of the adjoining Atlantic Intermediate water layer of Baffin Bay, suggesting that Baffin water intrudes along the seabottom of Lancaster Sound, beneath the Arctic Water layer (Collin 1963; Fissel and Wilton 1978). The shallow Barrow Strait shelf restricts the complete exchange of Beaufort Sea and Baffin Bay water, and effectively creates the two-layer structure of the Sound's water column. Collin (1962) estimated

that at 500 m depths, up to 92% of Lancaster Sound water originates from Baffin Bay.

Numerous and variant estimates of the net volume transport are available for the Archipelago (Kiilerich 1939; Timofeyev 1960; Bailey 1957; Collin 1960, 1962). Generally the total southward outflow from the Arctic Ocean, through the passages of Canada's Arctic Archipelago including Smith Sound, is calculated as about 54,000 km^3 per year (or about 1.7 million m^3/second). Smith Sound and Lancaster Sound may contribute approximately equal flows ($44x10^4$ and $49x10^4$ m^3/second, respectively) together comprising about one half of the total outflow. Jones Sound empties Arctic water into Baffin Bay at a calculated rate of $29x10^4$ m^3/second. Once again, oceanographers warn that these calculations, based on the 'dynamic method', are merely crude measures of trend.

Tides

Lancaster Sound tide predictions are based on decades of periodic water level measurements and, more recently, continuous records from automatic, internal recording tide gauges. The best tidal information for the Sound region is extrapolated from Resolute and published by the Canadian Hydrographic Service in Tides and Current Tables, Volume 4, Arctic and Hudson Bay. Walker (1977) reviewed the monthly values of mean/extreme water levels throughout the Archipelago. The best reference remains Dohler (1964) who describes tides of all Canadian waters.

The Sound's tides are predominated by the Atlantic Ocean, and almost negligibly influenced by the Beaufort Sea or Arctic Ocean. The tidal waves are propagated north through the Labrador Sea, Davis Strait, Baffin Bay and eventually from east to west through eastern Parry Channel (Figure 6). In contrast to the large mean tidal ranges (7.5 m) of Frobisher Bay, Dundas Harbour situated on Lancaster Sound's north shore experiences a much smaller range of 1.9 m. This value is about 38% higher than Resolute's tides, recorded 320 km to the west. The tide's diurnal component is about 1.5 times stronger than the semi-diurnal (Milne and Smiley, 1978).

Aside from tides, other sea-level variations are caused by rapid atmospheric pressure changes, strong persistent winds, and seasonal water

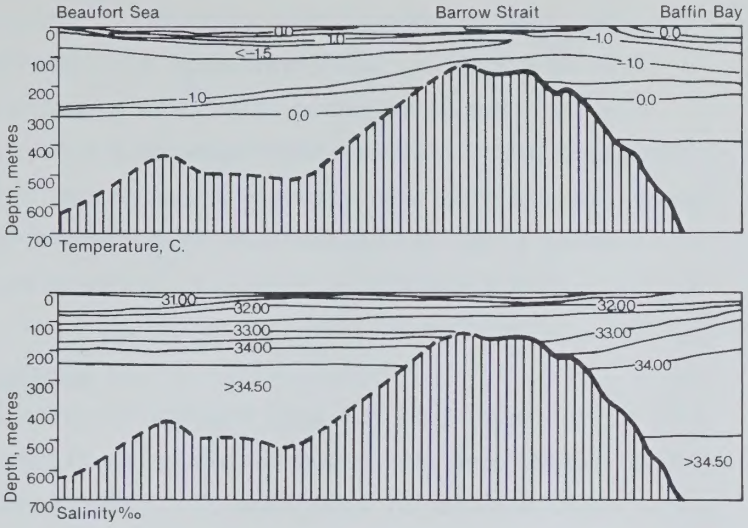


Figure 5 Longitudinal profile of Parry Channel, showing the shallow Barrow Strait sill which separates the Beaufort Sea and Baffin Bay water masses (Collin 1960).

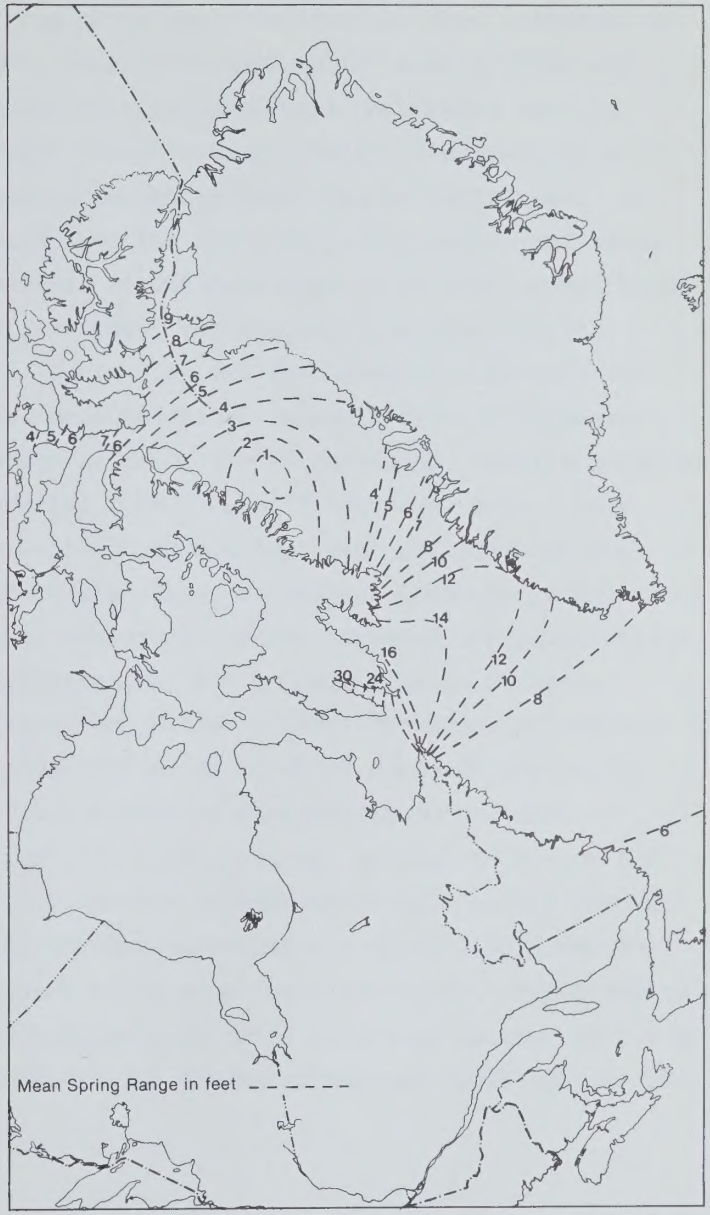


Figure 6 Mean tide range (in feet) in the Baffin Bay region (Dohler 1966)

density fluctuations during sea-ice melt and land run-off. In Lancaster Sound, such non-tidal influences are small, probably comprising less than 0.2 m of water level ranges. This contrasts with the southern Beaufort Sea; here onshore winds and accompanying storm surges abruptly cause rising waters of 3 m or so (Walker 1977).

Currents

Patterns of current flow are best measured directly using moored current meters (Fissel and Wilton 1978). In addition, valuable surface current information is indirectly derived by plotting ice-floe movements from consecutive satellite pictures, or by actual daily tracking of drifter buoys, again employing satellite technologies (Fissel and Marko 1978; Marko 1978). Unfortunately for this discussion, intensive 1978 and 1979 industry-funded oceanographic research in Lancaster Sound are not yet analyzed and interpreted. These studies are based on 112 current meter records at 34 locations, of which 16 were continuous for 12 months; 51 satellite tracks of drifter buoys; 20 satellite tracked icebergs; 176 upper layer current profiles; and about 50 tracks of oilspill followers. When available in 1980, these data will better assign means and ranges to various current components such as speed, direction and seasonal fluctuations within eastern Lancaster Sound and NW Baffin Bay. Of necessity, the following understanding of ocean currents relies heavily on a handful of published current meter records and satellite tracks.

During the ice-free season, oceanographers have measured tidal currents flowing in deeper waters at about 7 - 10 cm/second, usually oriented parallel to the Sound's east/west axis. Such velocities are not important, at least in the upper-water layer of eastern Lancaster Sound where large scale circulation currents are relatively much stronger, 100 cm/second or so at times (Fissel and Wilton, 1978). However, at deeper depths (500 m) or in other areas of the region, tidal currents of this magnitude are more important, accounting for as much as 50% of the flow variance. Mathematical tide models suggest that maximum tide currents equal 4.73 times the maximum tidal range over one cycle. For example, the extreme tide range at Dundas Harbour is 3.4 m; therefore the estimated maximum tidal current is

4.73 x 3.4, or 16 cm/second. In reality, measured tidal currents are sometimes two or three times swifter than such theoretical values, especially in coastal waters influenced by local seabottom relief and slope (Milne and Smiley 1978).

The large scale, persistent current along southern Devon Island has a measured average velocity of 50 cm/second or more to the west, at least during the ice-free season (PetroCanada 1979). At mid-South, the average magnitude of near surface circulation currents is about 30 cm/second, reaching speeds of 100 cm/second or more in some years (Fissel and Wilton 1978). Eastward flowing currents along the Sound's south margin flow at 25 to 50 cm/second on average. The Sound's east entrance is more variable; here the currents reverse in direction at times. Forty or fifty km 'downstream' of Lancaster Sound, the Baffin Current slows to 10 to 15 cm/second (PetroCanada 1979).

It is again stressed that these numbers are based on limited meaurements in eastern Lancaster Sound which may or may not poorly represent under-ice, winter circulation and fluctuations from year to year. In addition circulation currents change radically between locales as little as 30 km apart; this emphasizes the importance of small scale circulation features, such as gyres and eddies, particularly west of Croker Bay and away from the Sound's south margin. To add further complexity, the large scale, intrusive current appears to oscillate over a period of 10 to 20 days, with an amplitude of nearly 25 cm/second. The underlying cause is not understood (Fissel and Wilton 1978).

Of course, wind-driven currents can alter surface circulation patterns for short periods; it is calculated that a 90 km/hour wind storm can accelerate 'normal' surface currents to over 200 cm/second (Milne and Smiley 1978).

The overall impression of current complexity and variance is left without apology. With the possible exceptions of the eastward net transport of water and the intrusive flow from Baffin Bay, statements of general circulation and currents must be prefaced by the time and place of measurement. These same qualifications apply to the following descriptions, since the behavior of sea ice and icebergs are largely governed by near-surface currents. The difficulties of

trajectory predictions during oilspill cleanup, or pack ice/iceberg forecasting and avoidance become evident at a cursory glance.

Icebergs and Ice Islands

The bulk of iceberg information cited below was gleaned from de Lange Boom et al (1979) who tracked icebergs by radar in August and September 1978. The range of the radar was about 65 km, centred at Cape Sherard, southern Devon Island. Although these observations provide a better insight than most previous studies (Milne and Smiley 1978), these data represent only one summer of a particular year. Additional industry-funded radar and satellite-tracking studies in 1978 and 1979, when published, should better elucidate seasonal trends and drift patterns of the Sound's bergs. The prediction of berg drift, however, will remain difficult because of the region's characteristic fast drift, rapid acceleration and poor relationship with wind.

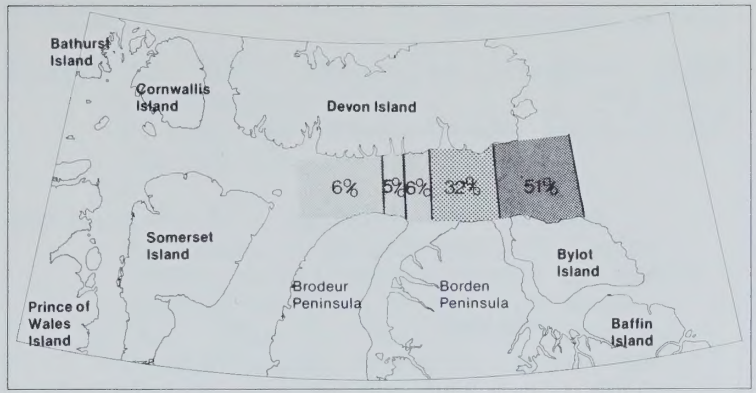
Between 1958 and 1976, Atmospheric Environmental Service ice reconnaissance flight recorded 1,400 icebergs in Lancaster Sound. The majority were sighted in August and September, usually close to the east entrance (Figure 7). Undoubtedly the iceberg hazard here is probably the highest of any Arctic Archipelago region. Baffin Bay bergs sweep as a steady stream into Lancaster Sound, most having originated from calving West Greenland glaciers. On the average, one or two bergs, sometimes up to ten, converge daily along southeast Devon Island. They 'migrate' swiftly (average 40 cm/second) past Cape Sherard along a narrow coastal corridor, often less than 30 km wide (Figure 8). Usually near Cape Warrander, this westward drift slows. The bergs turn south into mid-Sound, and begin a meandering confused drift eastward out of the Sound. Some bergs persist in their western intrusion into Parry Channel, occasionally penetrating as far as Wellington Channel (Milne and Smiley 1979).

As expected, iceberg circulation patterns are as complicated as the Sound's ocean current regime. The south Devon 'travel corridor' varies from 18 to 37 km in width. The fastest icebergs (speeds up to 60 cm/second) are observed within 15 km of the Sound's north shore, in mid-September of some years. Although strong northeast winds and

tidal currents sometimes account for such observed drift patterns, icebergs are generally driven by the Sound's large-scale currents such as the anti-clockwise intrusive current. Further out in Baffin Bay, icebergs usually drift slower, less than 20 cm/second and more often under wind influence.

In Lancaster Sound most icebergs are pinnacled (pyramind or cone shaped) although blocky and tabular types are common. Most icebergs fall into the 5 to 10 thousand tonne size class, but some range up to 2.5 to 5.0 million tonnes (Milne and Smiley 1978).

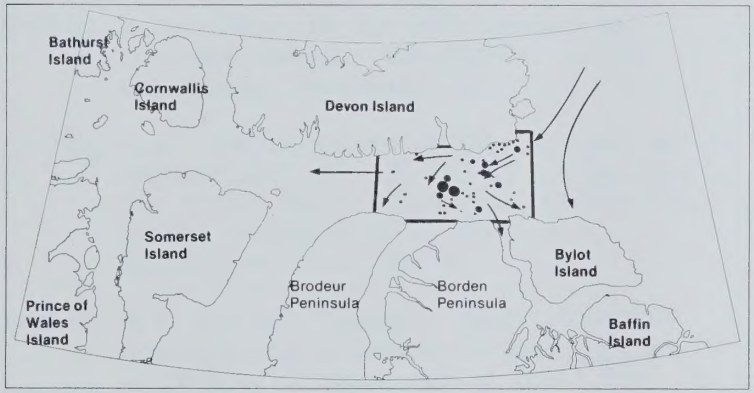
Bergs seldom originate from the Archipelago, although large fragments of the Ellesmere Island shelf ice have drifted through Parry Channel from 1963 to 1970. These so-called ice islands, up to 50 m thick, resemble rough multi-year floes, thus rendering them difficult to spot and presenting a hazard to navigation (Smiley and Milne 1979).



Icebergs

Percentage recorded by area in ice patrols

Number observed: 1,400 in years 1958 to 1976



Icebergs

Observed from survey vessel "Orion Arctic". Aug. 7 - Sept. 24, 1973

- Single bergs
- 2 - 4
- 5 - 10
- 11 - 20

Assumed drift Directions

Approximate Survey Area

Figure 7 Numbers, distribution and movements of icebergs in eastern Lancaster Sound (Milne and Smiley 1978)

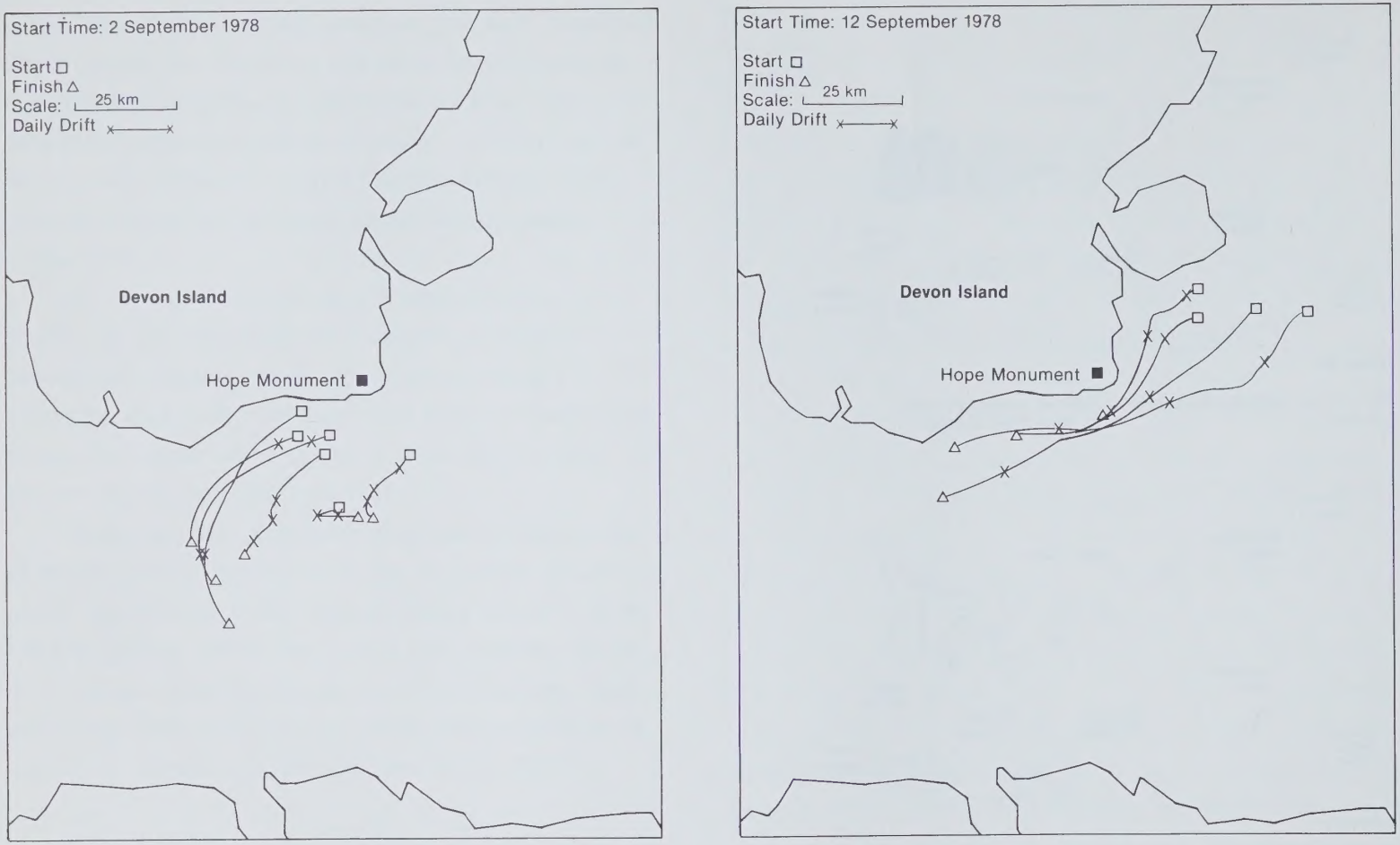


Figure 8 Movements of selected icebergs, based on radar-tracking of eastern Lancaster Sound from Hope Monument, SE Devon Island (de Lange Boom et al 1979)

References

Bailey, W.B. 1957. Oceanographic features of the Canadian Archipelago. J. Fish. Res. Board, Canada, 14, 5, 731-769.

Barrie, W.B., B.D. Bornhold, D.A. Hodgson, R.G. Jubb, P. McLaren and R.B. Taylor. 1978. Coastal reconnaissance for marine terminal planning in the High Arctic - III. Volume 1 - Main Report. Strategic Studies Branch, Transport Canada, 328 pp.

Collin, A.E. 1960. Oceanographic observations in the Canadian Arctic and the adjacent Arctic Ocean. Arctic 13: 194-201.

Collin, A.E. 1962. On the oceanography of Lancaster Sound. PhD Thesis, McGill University, Montreal. 204 p.

Collin, A.E. 1963. Waters of the Canadian Arctic Archipelago. pp. 128-139 in Proceedings of the Arctic Basin Symposium, October 1962. Arctic Institute of N. America, Washington, D.C. 313 pp.

Collin, A.E. and M.J. Dunbar. 1964. Physical oceanography in Arctic Canada. pp. 45-75 in Oceanogr. Mar. Biol. Ann. Rev. 2, H. Barnes, Ed., George Allen and Unwin. London.

de Lange Boom, B.R., M.R. MacNeill and J.R. Buckley. 1979. Iceberg tracking in Northwestern Baffin Bay and eastern Lancaster Sound from the Hope Monument radar camp. Seakem Oceanography Ltd. report to PetroCanada Exploration Inc., Calgary, Alberta. 215 pp.

Dohler, G. 1964. Tides in Canadian waters. Canadian Hydrographic Service, Environment Canada, Ottawa, 16 pp.

Fissel, D.B. and J.R. Marko. 1978. A surface current study of eastern Parry Channel, N.W.T. - summer 1977. Contractor Report Series 78-4. Institute of Ocean Sciences Patricia Bay, Sidney, B.C. 66 pp.

Fissel, D.B. and G.R. Wilton. 1978. Subsurface current measurements in eastern Lancaster Sound, N.W.T. - summer 1977. Contractor Report Series 78-3, Institute of Ocean Sciences, Patricia Bay, Sidney, B.C. 72 pp.

Greisman, P. and R.A. Lake. 1978. Current observations in the channels of the Canadian Arctic Archipelago adjacent to Bathurst Island. Pacific Marine Science Report 78-23. Institute of Ocean Sciences, Patricia Bay, Sidney, B.C. 127 pp.

Kiilerich, A.B. A Theoretical Treatment of the Hydrographic Observational Material. The Godthaab Expedition, 1928. Ned om Grøml. 78(5): 1-149, 1939.

Marko, J.R. 1978. A satellite imagery study of eastern Parry Channel. Contractor Report Series 78-5. Institute of Ocean Sciences, Patricia Bay, Sidney, B.C. 134 pp.

Milne, A.R., and B.D. Smiley. 1978. Offshore drilling in Lancaster Sound: possible environmental hazards. Institute of Ocean Sciences, Patricia Bay, Sidney, B.C. 95 pp.

Meunch, R.D. 1971. The physical oceanography of the northern Baffin Bay region. The Baffin Bay/Northwater Project, Scientific Report 1. Arctic Institute of N. America, Montreal. 150 pp.

PetroCanada. 1979. Initial Environmental Assessment: Proposed Baffin Bay exploratory drilling program. Calgary, Alberta.

Pelletier, B.R. 1980. Geology and Physiography. Background Report Series, No. 1, Lancaster Sound Regional Study, DIAND. Ottawa.

Sekerak, A.D., R.A. Buchanan, W.E. Griffiths, M.G. Foy. 1976. Biological oceanographic studies in Lancaster Sound, 1976. LGL Ltd. report for Norlands Petroleums Ltd., Calgary, Alberta. 169 pp.

Smiley, B.D., and A.R. Milne. 1979. LNG transportation in Parry Channel: possible environmental hazards. Institute of Ocean Sciences, Patricia Bay, Sidney, B.C. unpublished manuscript series.

Sowden, W.J. 1980. Ice Climatology. In Background Report Series, No. 1, Lancaster Sound Regional Study, DIAND. Ottawa.

Timofeyev, V.T. 1969. Vodniye Massy Arkticheskogo Basseina. Gidrometeirologicheskoe Izdatelstvo, Leningrad, 190 pp. (translated by L.K. Coachman, University of Washington, Seattle, June 1961).

Walker, E.R. 1977. Aspects of oceanography in the Archipelago. Note 3, Institute of Ocean Sciences, Patricia Bay, Sidney, B.C. 186 pp.

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